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AN

INTRODUCTORY TREATISE

ON

THE NATURE AND PROPERTIES

OF

LIGHT,

AND

ON OPTICAL INSTRUMENTS.

BY W. M. HIGGINS.

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PREFACE.

More than two thousand years have passed away since Aristotle, the earliest writer on Optics, whose Treatise has outlived the ravage of time, penned his unsuccessful paper. About fifty years after the celebrated Euclid wrote his *Οπτικα,* in which he maintains that, "Visual rays issue from the eyes in diverging right lines, so as to form a pyramid, or cone, whose vertex is in the eye, and whose base encircles the object we contemplate." In 218, B. C., Archimides flourished; and a few years afterwards Ptolemy Euergetes fixed his great mirror on the tower of the Pharos at Alexandria. In the twelfth century, the celebrated Arabian Philosopher wrote his Treatise; afterwards published under the title of Thesaurus Opticæ; and during the three following centuries arose Bacon, Porta, Maurolicus and Kepler. The seventeenth century produced Antonio de Dominis, Harriot, Boyle, Hooke, Grimaldi, Leibnitz, Barrow,—and the pride of England, Sir Isaac Newton. Since the days of Newton the science of Optics has been held in universal esteem, and may be fitly denominated the most beautiful and diversified of the Physico-Mathematical sciences.

To aid the progress of this study, the following work has been written; and the author, hoping to assist those who, like himself, are climbing the hill of science, has prepared, as a companion to this, a series of introductory papers on the pure sciences and Astronomy, which Treatises will shortly be published. To urge the necessity of Mathametical learning is unnecessary; for as the moon increases or wanes according to her position with the glorious luminary, so science waxes or decays as she is united to, or forced from the Mathematics. When these are combined, the hand of science is, indeed, mighty, and truly the Philosopher is greatly honoured. He combats nature with her own weapons, and to the honour and glory of England let it be remembered, that after nearly six thousand years, in which mankind had been struggling to obtain the superiority over nature; in which Archimedes, and the most illustrious ancients had joined, inventing screws, wheels, and springs; an Englishman vanquished her with a vapour.

With regard to the opinions maintained in this work, concerning the nature of light, it is only necessary to say, that although in some degree novel, they have not been embraced without investigation. Persevering study and frequent experiments have been resorted to by the author, yet he has constantly avoided introducing his theory when unnecessary for the explanation of phenomena.

I cannot, however, commit this work to the public without returning my acknowledgments to those gentlemen who have assisted me, by their advice and by other means, in the arduous task. Nor shall I ever forget the condescension of my Royal Patron, who has so graciously forwarded my purposes, by his encouraging patronage. The names too of Brougham, Capell, Pond, and others, who have excited my early researches by their effective support, will ever be held sacred in my memory, and the remembrance of the past will constantly urge me to pursue with unremitting energy the work I have undertaken.

CONTENTS.

PART I.

CHAP. I. — *On Matter and its Properties.* 1

CHAP. II. — *On the Nature of Light*.................... 10

CHAP. III.—*On the Production of Light by various substances* . 19

CHAP. IV.—*On the Influence of Light upon Vegetables,—its production by them,—its Chemical and Magnetical effects, &c.* 24

PART II.

ON REFLECTION.

CHAP. I. — *On the Cause of Reflection*.................... 29

CHAP. II. — *On the Laws of Reflection* 35

CHAP. III.—*On finding the Foci of Plane and different Curvilinear mirrors* 42

CHAP. IV.—*The appearances under which bodies are observed when their images are seen after reflection from plane, convex, concave, and cylindrical mirrors* .. 46

CHAP. V. —*History of several discoveries relative to the Reflection of Light* 55

PART III.

ON REFRACTION.

CHAP. I. — *On the Cause of Refraction*.................. 61

CHAP. II. — *On the Laws of Refraction* 64

CHAP. III.—*On finding the foci of Rays, refracted by passing out of one medium into another of different density.* 73

CHAP. IV.—*On the appearance under which objects are seen when their images are viewed after Refraction, through media, whose surfaces are plane, concave, or cylindrical.* 76

CHAP. V.—*History of several discoveries relating to Refraction of light* 80

PART IV.

ON OPTICS, OR THE THEORY OF VISION.

CHAP. I. — *On the Anatomy of the Eye* 84
CHAP. II.— *History of several discoveries relating to Vision* .. 94

PART V.

ON CHROMATICS, OR THE THEORY OF COLOURS. 97

PART VI.

ON INFLEXION 106

PART VII.

ON DOUBLE REFRACTION. 112

PART VIII.

ON POLARISATION OF LIGHT.

CHAP. I.—*Introductory Remarks* 118
CHAP. II.—*On the Polarisation of Light by Reflection* 121
CHAP. III.—*Polarisation of Light by common Refraction, and its Laws* 125
CHAP. IV.—*On the Polarisation of Light by Double Refraction.* 127
CHAP. V.—*On the Colours exhibited by crystalised plates, when exposed to polarised light, and of the polarised rays surrounding their optic axes* 129

PART IX.

ON THE APPLICATION OF THE PRECEDING FACTS AND THEORIES TO NATURAL PHENOMENA 136

PART X.

ON OPTICAL INSTRUMENTS.

CHAP. I. — *On Spectacles.* 144
CHAP. II.— *On Telescopes.* 147
CHAP. III.—*On Micrometers* 154
CHAP. IV.—*On Microscopes* 161
CHAP. V.— *On Instruments used for Optical Observations, on and under Fluids, &c* 165

TO

HIS ROYAL HIGHNESS

THE DUKE OF CLARENCE, K. G.

LORD HIGH ADMIRAL,

&c. &c.

Your Royal Highness,

THE condescension your Royal Highness evinced in permitting me to place the following work under your Royal Highness's patronage, impresses the mind with a conviction, which we have long felt, of your Royal Highness's desire for the wider spread of knowledge, and the gracious endeavours you make to promote that end. It has often been casually remarked, that the first element of national character is the nature of the country which acts previously to all other influences, and is moulding the mind before the legislator can form his institutions. However this may operate in producing a love or distaste for the glowing imagery of poetry, the extended range of the British empire and its glory, may, in no unimportant degree, be attributed to the patronage which the philosopher has enjoyed, and the application of the knowledge he has acquired by British sailors.

Though it was once little less than a prodigy to visit "Ultima Britannia," she has long emerged from her ocean of ignorance. Blessed by a noble constitution, and governed by a race of mighty monarchs, her sons are daily giving example of what they can do in the cause of liberty; and she now stands second to none in martial prowess or learning, "the envy of surrounding nations, the admiration of the world." As the rocks which guard her fertile fields withstand the power of the proudly raging sea, so may she raise herself against the force of every foe; and may the British sailors under the smiles of your Royal Highness demonstrate to the offending nations, as the brave ones of Navarino have recently done, that their past gallantry is but an earnest of what they can do, and that those of her sons who have defended her in war and elevated her in science, are only a sample of the rest of her children.

I am, with the most profound respect,

Your Royal Highness's

Most obliged & most obedient humble Servant,

W. M. HIGGINS.

Chatham, March 10, 1828.*

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* This dedication received the approval of my Royal Patron when the British sailors were under the wise command of his Royal Highness, nor will they ever forget his gracious condescension; for not only did he reward valour where he discerned it, but elevated many to that rank in their profession which their long service demanded, although their interest had been too small to advance them. It will perhaps appear, that under so gracious a patron, I might long since have presented my work to the public; but the magnitude of my undertaking, and many other circumstances have prevented me: yet I trust the delay will render it not the less acceptable to my subscribers.

A TREATISE

ON

OPTICS.

PART THE FIRST.

CHAPTER I.

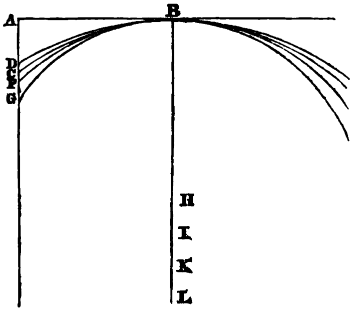
On Matter and its Properties.

MATTER is that existence which is the object of our senses. The properties usually assigned to it are, IMPENETRABILITY, EXTENSION, ATTRACTION, FIGURE, MOTION, REST and INERTIA. It has been supposed by some that these are not the only properties of matter, but that it is possessed of others, which, though unknown, may be the causes of known effects.

Matter is generally allowed to be composed of lesser parts of great minuteness, and from this supposition arises the question of its IMPENETRABILITY. All the philosophers who have written on the subject may be divided into two classes; such as believe matter to be penetrable, and such as suppose it impenetrable. Among the latter class stands Sir Isaac Newton, whose opinion is an epitome of the hypotheses of all. "It seems probable to me, that God in the beginning formed matter in solid, massy, hard, IMPENETRABLE, moveable particles, of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which he formed them; and that those primitive particles, being solid, are incomparably harder than any porous bodies compounded of them, even so very hard as never to wear out, nor break in pieces; no ordinary power being able to divide what God himself made one in the first creation."

But if the IMPENETRABILITY of matter be allowed, numerous pressing difficulties must occur in the explanation of some abstruse phenomena. The sequent theory has therefore been advanced, and appears to possess several advantages over the other. If it be allowed that matter is composed of such lesser parts that the ultimate particles be infinitely little, then matter may be allowed to be PENETRABLE; for in this case, an infinite number of particles can make but one finite mass, how large, or how small soever that mass may be. Suppose one of these ultimate particles, infinitely small, to be surrounded with a repulsive medium, which should exert its force for a finite distance around that particle. Let another of these ultimate particles, surrounded in the same manner, approach the first, they will be kept from actual contact by the mutual action of their proper repulsive forces, and will therefore occupy a finite part of space, or are possessed of extension, and all the common properties with which it is usually supposed matter is endowed, they also have figure, and are capable of either motion or rest. If by any means the repulsive forces, exerted by these two particles, be overcome, they necessarily can exist together; and in the same manner can any number of them without occupying any finite part of space.

As the whole of this reasoning hangs upon the doctrine of the *Infinite minuteness* of the particles of matter, it is necessary to prove that *if the ultimate particles of matter be extremely and infinitely small, then matter is divisible ad infinitum.* That this is the fact is easily proved. Let B L and A G be parallel, and A B perpendicular to them; then with the centres H I K L, and radii H B, I B, K B, L B, describe the arcs G B, P B, C B, D B. Now the line B L may be infinitely extended, and therefore the distance of the point A from the point D may be infinitely diminished. Suppose the radius B L infinitely long, then the point D of the arc A B would not coincide with A; although the distance would be infinitely little; for the line A B, being a tangent to the circular arc in the point B, could coincide with it in no other point whatever; therefore the space A D may be divided into an infinite number of parts.



If the truth of the hypothesis be allowed, it will appear that matter is CAPABLE OF EXTENSION, although its parts may be infinitely small; and it is PENETRABLE, or else any number of parts can exist together in one place, at the same time. It is also capable of FIGURE, MOTION, and REST. The attractive influence, which is usually assigned to matter, appears to be only a modification of the repulsive, with which, as we have before stated, it is endued. These forces are spread over each other as laminæ, covering the ultimate particle; the repulsive force encircles and envelopes the particle, and degenerates into an attractive power which binds the whole combination of particles into one mass. This alternate change may be illustrated by the change of positive into negative electricity, and negative into positive, in that curious electrical phenomena, "The Zones."

INERTIA has been assumed as an indispensible property of matter, but gratuitously if Sir Isaac Newton's first rule for philosophising be admitted. Let any ultimate particle of matter, surrounded by its spheres of attraction and repulsion, not possessing any vis inertiæ, nor any property which might be the cause of that, be brought into violent concussion with another similar particle at rest. As their spheres of attraction offer no resistance to the moving particle, but, in fact, increase its velocity, it is urged, with an accelerated motion against the others; but they are afterwards seperated by the repulsive influence which they severally possess. When they have separated the sum of the distances of their respective spheres of repulsion, they again attract each other; and must consequently remain at that distance from each other, as they are mutually exerting two opposite influences. From this it may be deduced, that the resistance which the moving particle experienced in its endeavour to move the particle at rest, did not arise from any sluggishness in that particle, but the resistance it met with from its repulsive influence, and therefore the particle itself was perfectly passive.

When a mass of matter is under consideration, the case is much the same; but here the percussive mass must have sufficient velocity to cause an impression to be made in all the particles which lie in the direction of its motion. As an elucidation, let a cubical dice be violently projected against a thick pasteboard, and let the dice strike the board with the plane of one of its sides; if the force with which the dice move, be sufficient to create a repulsive force in all the spheres of the particles with which it is in contact, the board will necessarily move, all the particles which lie out of the plane of percussion accompanying it, by reason of the influence of their spheres of attraction. If the motion of the dice be so violent as to cause the particles lying under the plane of percussion to move out of the spheres of attraction of their neighbouring particles, the board is instantly rent, and the piece violently impelled forward.

We are now to inquire into the cause of Motion. The great question, What is the prime cause of motion? has been agitated for more than three thousand years. The schemes which the Tartalian problem has given rise to are infinite. Mocked in their hopes, philosophers have now almost given up the inquiry.

Des Cartes defined motion to be the act of a body changing place; and considered it inherent in matter. Many of the ancients held the same doctrine. Pythagoras said, that matter contained within itself a PRINCIPLE of motion; that nature and all natural bodies were animated; and that there was an active principle in matter, which he called the soul of the world. Empedocles taught the same doctrine; and Plato said, That God had in the beginning impressed all matter with such motion as was proper for it.

Newton taught that motion was not inherent in matter, and that matter was naturally INCAPABLE of motion. In this he followed some of the greatest masters of antiquity. Democritus the Thracian, believed that the first elements of bodies, (or what a modern philosopher would call their ultimate particles,) were totally void and inapt of all qualities, and naturally incapable of motion. Epicurus said, that matter could not possess cold, colour, heat, motion, nor any other quality: and Aristippus the Cyrenian, was of a similar opinion. Sir Isaac Newton believed that the cause of motion was of a spiritual nature, generating that attraction and repulsion, of which he made such an eminent use. To affirm that motion is inherent in matter, is absurd, and Sir Isaac's supposition, that their is an ether which is the immediate cause of motion, has a greater appearance of truth. But Newton's own rule again presents itself to our minds, and we are induced to ask, what need is there of this ether? It certainly seems an improbable agent, and in many cases is inefficient, for motion sometimes depends on the mere volition of the mind.

Bishop Berkley introduced an hypothesis to account for motion, which he thus explains; "According to the Pythagoreans and Platonics, there is infused through all things πυρ νοερον πυρ τεχνικον, an intellectual and artificial fire, an inward principle, animal spirit, or natural life, producing and forming within, as art does without, regulating, moderating, and reconciling the various quantities and parts of the mundane system. By virtue of this life, the great masses are held together in their ordinary courses, as well as the minutest particles governed in their natural motions, according to the several laws of attraction, gravity, electricity, and magnetism."

Hypotheses without number have been proposed since the time of Newton, but they are all liable to the objections which have been made to his.

To prove the falsity of Des Cartes' notion, of the inherency of motion in matter, is an easy task. If motion be inherent in matter, it should follow regular and fixed rules, but the fact is the reverse. The mind desires some object, and the hand obeying some unknown impulse is stretched out, and obtains possession of it. But why did the hand stretch out, was the motion innate in it? It was not, for it depended on volition, the mind, and the mind alone, was the true cause of the motion.

Berkley's system is confessedly derived from Plato's "ANIMA MUNDI." Now if this natural life, or animal spirit be a secondary agent, it cannot be sufficient for the purpose for which it was intended; and if it be considered as a primum or independant agent, the hypothesis is atheistical. That the latter was the opinion of Plato we cannot doubt.

With regard to Sir Isaac Newton's hypothesis, we may perhaps be allowed to remark, that the difficulty we have already mentioned, will ever be an objection to it. If the ether or essence, which is the cause of the motion, be what he seems desirous to make it, its actions cannot be effected by volition, or it is something very similar to Plato's anima mundi.

The greatest praise that can be awarded to the hypotheses of motion, which have been invented since the days of Newton, is, that they are the essence of mysticism. There is something so unaccountably perplexing in the conception of their doctrines, that after inquiry, the mind is in a very improper state for the reception of a conviction of their accuracy. To me they appear far more adapted to please the disciples of Kant, than of Newton; but at the same time, it is impossible to deny that they are elegant specimens of metaphysical disquisition.

After all that has been written on the subject, by the greatest men, we must confess that nothing has been proved, but that "it is past finding out." There are, however, many other phenomena around us, and of common occurrence which are equally unknown. Motion, or rather the cause of motion, is evidently incomprehensible by the senses allotted to us. Whatever ethers, essences, or spirits, may be invented, still the question recoils on the inventor, From what do they receive their power to cause motion? Surrounded on every side with insurmountable difficulties, the only resource which the mind has, is in an infinitely superior Being, whose counsels and ways must inconceivably surpass in wisdom the most elevated thoughts of the wisest of his creatures, as his power must excel their utmost conceptions.

The EXTENSION of matter has also been long debated, and philosophers have exerted their utmost powers to support the opinions they had formed, some to prove that matter is finite; others, that it is infinite in quantity. The idea of infinity is conceived by the repetition of the parts of any thing which can be divided. In this manner we can conceive an inch to increase till it be infinitely long, by supposing another inch to be added to it an indefinite number of times; and in the same manner, by increasing any duration, the idea of eternity is acquired. But there are things of which only a finite idea can be conceived; for an object may be of a particular colour, and although we add never so much of that colour, we cannot suppose it infinitely more coloured. But matter is that which can be infinitely divided, and consequently may exist infinitely, or have infinite extension. The idea of space without matter is quite incomprehensible, and indeed seems a direct contradiction. From this it would appear, that there is no part of space, how small soever it may be, that is not possessed of matter, and therefore the extension of matter is infinite.

CHAPTER II.

On the Nature of Light.

THE similarity between light and sound occasioned similar hypotheses to be adduced for the explanation of their properties. It has been long known that the propagation of sound consists in undulations occasioned in the air by a vibrating body. It was therefore supposed that light was occasioned by the undulations excited in an ether of extreme rarity. The rays of the sun, striking upon this medium, were said to cause undulations in it, which, instantaneously reaching the eye, caused that sensation in it which we term light. This hypothesis was proposed by Des Cartes.

Very long, however, before the time of Des Cartes, an hypothesis of a similar nature was promulgated by Aristotle. He supposed light to be occasioned by the action of a subtile, pure, and homogeneous matter or ether which the sun put in motion. Though it is not expressly said that undulations were occasioned, yet as much may be inferred.

This hypothesis has found its advocates among the first class of philosophers. Euler, who was one of the greatest mathematicians, was one of its ablest supporters; and even in the present day there are converts to Euler's reasoning.

The arguments usually adduced against it are the following:—

1. That undulations, whether in an elastic medium,

or on the surface of a non-elastic medium, after meeting with an obstacle which has an aperture, should pass through that aperture, and diverge from it as from a centre. This is easily evinced by actual experiment; and from this it is evident, that when light is transmitted through an aperture into a darkened chamber, that chamber should be quite illuminated, how small soever the aperture may be: this is not, however, the result of the experiment—therefore the undulatory hypothesis of light is not correct.

2. When undulatory waves meet with any obstacle they should deflect laterally after passing it; and if light be obstructed by any obstacle, by analogy, the same thing should take place. But the result is the reverse, for shadows are never enlightened by incident light; the indistinctness of their extremities arises only from the opaque particles floating in the adjacent air; and, therefore, the undulatory hypothesis of light is not correct.

3. Sounds are heard through tubes how bent or sinuous soever; but if a tube be in the least bent from a rectilinear form, it effectually prevents the passage of any light. Besides the ether, which is the very soul of this doctrine, is almost universally conceived to be nothing else than rarified atmospheric air, it therefore follows that a vacuum, or place deprived of air, should be perfectly dark and unfit for the transmission of light, not to mention the difficulty of accounting for transparency, opacity, &c.

This doctrine was exploded by Sir Isaac Newton, who taught that light is not a fluid *per se*, but consists of a vast number of exceedingly small particles, which are emitted in all directions from the lucent body through the medium of a repulsive force. These particles are thrown out with an amazing velocity in right lines, and may be deflected out of their course by three different circumstances, denominated Reflection, Refraction, and Inflection ; they may, however, likewise undergo another process, called extinction.

This theory, as far as it goes, is evidently a collection of facts sufficient to explain almost every optical phenomena, and is therefore beyond successful controversy. That the particles of light are exceedingly, and even infinitely small, is evident, for through an aperture 100th part of an inch in diameter, nearly the whole hemisphere may be seen. Therefore particles of light, reflected from every particle of the prospect, are continually passing through that small aperture. How inconceivably small, therefore, must those particles be! That these particles are emitted or ejected in every direction is plain, since a lucid object may be seen in every direction, except when some opaque body intervenes. A repulsive force is necessary to effect the ejection of these small particles. Some have supposed this force to be inherent in the sun; but the truth is, that it is inherent in the light, as will be shown in the following proposition.

Lemma,

The particles of light which are commonly supposed lucid in themselves, are not so in fact; and this will appear by considering that the effect is produced in the organs of vision, and not in the light itself. There are subjects which are blind, and yet no outward appearance of it exists. They cannot perceive the light, for their eye, or organ of vision, cannot receive the effect of the incident particles,—it is the effect which is taken for the cause. The particles of light may be of an opaque and dark nature, and yet excite the notion of light. This is occasioned by the particles falling upon the organs of vision, and there exciting that sensation denominated light. Every one is aware that this sensation may be at any time produced by pressing with the finger upon the eye, which will produce white, red, orange, and every other colour; and from this it appears, that when any force is applied, sufficient to irritate the visive organ, the idea of light is produced.

Proposition. Theor. When the spheres of attraction which surround any particles of matter are destroyed, those particles produce light.

In demonstrating this proposition it is necessary, first, to consider the effect which would be produced on the admission of the conditions of the proposition. If the attractive influence of these particles were annihilated, there being no reaction opposed, the repulsive forces would act with their utmost energy; but as the ultimate particles are infinitely little, they will be repelled with an insuperable force, each particle affecting those adjacent to it; consequently, their energy continues, and therefore their velocity; but as these particles are infinitely small, they pass through the humours of the eye, and according to the preceding lemma, necessarily occasion the sensation denominated light.*

---

* A farther attempt to exemplify the truth of this hypothesis will be made when we speak of the production of light.

The amazing velocity of light was discovered by Mons. Rœmer, a native of Arthusen in Jutland, whilst making observations on the satellites of Jupiter. Before his time, it had been the opinion of philosophers that its motion was instantaneous. Aristotle expressly says so; Chrysippus the Stoic, who was the successor of Zeno, taught the same thing, and illustrated it by a long rod, which pushed at one end, the other end instantly moves.

When the Earth is between Jupiter and the Sun, the satellites of that planet appear 8¼ minutes earlier than they should according to the times of their appearance as calculated in accurate tables. When the Sun is between the Earth and Jupiter, the eclipses happen 8¼ minutes later than the calculated time. This can only be accounted for upon the supposition of the progressive motion of light; it therefore will appear that light requires about 16½ minutes to perform its passage across the orbit of the Earth that is 190,000,000 of miles, or about 200,000 miles in a second.

From observations upon the fixed stars more especially $\varkappa$ Draconis Dr. Bradley discovered that they had an apparent elliptical motion about their mean places every year; this he called their aberration and discovered that it was occasioned by the combined motion of the Earth in her orbit, and the progressive motion of the Earth. The proportion of the velocity of light to that of the Earth, in her orbit is as 102 to 1, and therefore light moves from the sun to the Earth in 8′. 12″. These facts confirm the observations of Rœmer, afford a powerful argument in proof of his theory, and demonstrate that all light whether direct or reflected, moves with equal velocity.

The disciples of Plato discovered that all light is emitted in right lines diverging from the lucent body, the truth of which will be proved by considering the manner of the emission of light, or the projection of the particles producing light. Suppose a number of these particles just projected by their repulsive energy, each particle will as much as possible endeavour to recede from the influence of the others. As the actions of all are equal, this recession will be equal, increasing as the square of the distance from the radiant body. No one of the particles can move on one side either up or down, if one should, to effect this it would be necessary to approach nearer one of the neighbouring particles and recede from another, which would be against the laws of reason and nature, therefore light is emitted from the lucent body diverging in right lines.

Notwithstanding the ease and elegance which characterize all attempts which are made to account for Optical phenomena upon these principles, there have been and are men, of the greatest talent and learning, who have supposed light to be an immaterial essence. It is said that Timæus who wrote a Treatise "on the Nature of the Soul of the World," was one of the supporters if not the founder of this theory. But if light be of an immaterial nature not being acquainted with its properties it is impossible to account for Optical phenomena in a natural manner. Besides it is generally supposed to be omnipresent, and this being granted, the progressive motion of light proves it to be material. The objections raised against the doctrine of the materiality of light are very unimportant and unworthy our notice. But unanswerable difficulties are urged against the immateriality of light, and nothing can be more unlike a philosophical act than to place in the stead of known agents, whose manner of operation is understood, unknown and fictitious essences of whose very being there is a doubt. Lastly, if light be an immaterial essence, Reflection, Refraction, and Inflection cannot be accounted for, as it cannot be supposed that a material lifeless mass of matter can act upon an active and immaterial agent.

There is another hypothesis which considers Light, Electricity, Heat, Magnetism, &c., as modes of one essence, but as this does not belong to the science of Optics, but rather to that of Physics, it is omitted as well as all other similiar theories which have been invented to answer certain objections, as it is presumed that the preceding hypothesis will not only explain every phenomenon in the science, but that only futile and easily answered objections can be advanced against it.

When any Chemical, Mechanical, &c. means are employed in operating upon matter it frequently happens that light is emitted. To explain this it is necessary to revert to the proposition. Here it may be necessary to observe that combustion destroys the attraction of the ultimate particles of matter except in very few cases and therefore where combustion is excited it is reasonable to expect that it will be accompanied by emission of light.

The most prominent case is that of a taper or candle. By the application of heat it is put into a state of combustion and is consequently followed by light. The case is as follows:—The wax or tallow of the candle being melted ascends by capillary attraction along the fibres of the cotton, and, having reached a certain point, the heat which is applied causes it to boil, or rather decompose, which furnishes carburetted hydrogen. This gas combines with the oxygen of the surrounding air, during combustion, and gives out its carbon partly in a state of infinite comminution, and partly in a conglomerated state. The conglomerate particles ascend but those whose attraction is entirely destroyed, enter the eye, and produce the sensation called light.

During the accension of combustible bodies, light is produced in a similar manner. The percussion of a flint and steel gives a practical example of the truth of this theory. The percutient force causes an atom of the steel to be struck off, which in its passage through the air, gives out a brilliant light which is caused by the action excited between it and the air.

That heat occasions a repulsive force is evident in all the gases, and is daily seen in the powerful effects of steam. When the heat to which steam is subjected becomes so great as totally to destroy the attractive forces of the particles, it begins to shine, and would, if confined, split a rock asunder, or throw the most impregnable fortress like dust into the air. How great then must these repulsive energies be.

By vehemently rubbing two pieces of smooth hard wood together, and thereby causing their more prominent parts to come within the spheres of attraction, light may be procured. In this manner the New Zealanders and other savages obtain fire for their domestic and culinary purposes.

The light which so brilliantly illuminates many electrical experiments is occasioned by the passage of that fluid through the air, when, by its amazing energy, it counteracts and overcomes the attraction of the particles of air which surround it. That this is the case is without doubt; for when the fluid is made to move through a perfect vacuum it is invisible save that a milky whiteness is left in the path which it has taken. And it is well known, by those who are accustomed to electrical experiments, that the more condensed the air the more vivid the spark.

Decomposition is another chemical source in the production of light. When bodies of an animal nature are undergoing this process, they are not so liable to shine as fish. If the back bone of a fish be exposed and allowed to approach to a state of putrification, it will give out light. This may be rendered a certain result, if the quantity of flesh left on the bone be too small to undergo the process of putrifaction, and be in such a state that the aqueous juices shall not completely evaporate. That decomposition is the cause of this is evident, for in an exhausted receiver the lucid appearance ceases; and also if the bone be varnished with resins or dipped in alcohol.

CHAPTER III.

On the Production of Light by Various Substances.

The most notable chemical production of light is in the phosphori and pyrophori. Phosphorus always shines when exposed to the air, (whether it has been exposed to light before or not,) and from this property its name is derived. But there are other descriptions of phosphori which require exposure to the light before they will shine in the dark. The pyrophori, when in contact with the air, occasion a violent accension.

In common phosphorus the light is produced by chemical decomposition; for upon exposure to the air, its affinity for the oxygen being considerably greater than that of the nitrogen, it begins to decompose the surrounding air, slowly seperating the oxygen and forming phosphoric acid whilst the nitrogen is disengaged, a part of it in a conglomerated state and another part having its attractive influence destroyed conforms to the condition of the proposition, and therefore produces light.

Some preparations, as Baldwin's and the Solar phosphorus, require exposure to the light before they will shine. Baldwin's phosphorus is the nitrate of lime calcined till its water of crystallization is evaporated,—when this preparation is exposed to the light and immediately carried into a dark chamber it emits a vivid light. The solar phosphorus, which is the most powerful of any, is made of shells of oysters stratifie[illegible] with sulphur, and subjected to a red heat for two hours. Its manner of operation is exactly similar to that of Baldwin's.

The phenomena of this class of substances has given rise to many theories. It has been supposed that these bodies act by absorption of the light and subsequent emission; but if this were the case, the same colour of rays which fall upon the phosphorus should be emitted by it, which is not the case. Perhaps it may be accounted for by supposing that the incident light is totally deprived of its velocity, but that by putting the internal particles of the substance into a state of chemical action, whilst undergoing that operation, light is thrown out.

The real cause of the Will-with-a-wisp, or Jack-with-a-Lantern, as it is vulgarly called, was long undiscovered. Mr. Bradley supposed it to be a swarm of luminous insects, and Mr. Ray was of the same opinion. By the generality of the peasantry it was supposed to be a naughty sprite, whose business it was to delude the poor traveller into ponds and boggy places, and by then depriving him of the use of its light to leave him to extricate himself from his awkward situation. Milton describes it in his usual powerful language,

> A wandering fire
> Compact of unctuous vapour, which the night
> Condenses, and the cold environs round,
> Kindled through agitation to a flame;
> Which oft, they say, some evil sprite attends,
> Hovering and blazing with delusive light,
> Misleads the amazed night-wanderer from his way,
> To bogs and mires, and oft through pond or pool,
> *There swallowed* up and lost, from succour far.

Though we admire the poet's glowing description of this curious phenomenon, we cannot receive his definition. It is of two genera; the one being Phosphuretted hydrogen gas which inflames at the temperature of the atmosphere, and, in the same manner as we have already described, gives out light. The other is occasioned by an animal vapour, which is strongly electrified and overcomes the attraction of its ultimate particles. The St. Helme's fire and Stellæ Cadentes are electrical phenomena.

Light exists in another form in the Lampyris and other insects, differing from all the preceding in its appearance. The glow worm, (Lampyris Noctiluca) is frequent in some parts of England, and shines with a strong light, but is far exceeded by the Elater noctilicus, an insect of the beetle tribe which is highly endowed with this property, "This insect which is an inch long, and about one third of an inch broad gives out its principal light from two transparent eye-like tubercles placed upon the thorax, and the light admitted from them is so considerable that the smallest print may be read by moving one of these insects along the lines."* This curious insect is a native of the West India islands.

This luminous appearance is not as some have supposed voluntary, for after the death of the insect, it continues for a short time, although its increase or decrease may be so, since the insect by elongating or shortening itself, may leave more or less of the luminous parts exposed. The lucent appearance of the glow worm originates in a liquor situated at the extremity of the insect, and if suffered to dry upon the hand, it soon loses its beauteous glory. The light emitted has its origin in the same manner as the phosphori.

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* Introduction to Entomology, by Kirby and Spence.—Vol. 2. p. 41[illegible]

Wood undergoing decomposition, (in which state it is usually called rotten wood,) frequently assumes a shining aspect which never appears until it is in that state. So soon as the decomposition is retarded, the lucidity ceases as is the case in vacuo or when placed in frigorific mixtures.

Certain fishes also have the same property, as the Pholas. This was known to Pliny who discovered that it was owing to a fluid on the surface of the insect. It is very probable that the cause is much the same as in the Lampyris. There are two particular distinctions of lucidity to be observed; first, when the fish is alive, which is owing to the fluid spread over it, but when it dies, the light disappears, until it has become putrid, the light then reappears, which is owing to incipient decomposition. Water or any liquid containing oxygen does not at all diminish the lucidity in the first instance, but if the fish, after death, be immersed in alcohol, brandy, oil, &c., or placed in vacuo, it very soon dies away. That the phosphoric fluid is the cause of the light in the living animal is evident, for if milk, rendered luminous by means of it, be enclosed in tubes, it will not shine till bubbles of air are admitted.

The most common production of light is in flesh just before it undergoes the process of decomposition. A milky lucidity emanates from it which only continues so long as the flesh is moist, when it is siccated the lucidity vanishes, and after the decomposition has arrived at that point when an oleaginous fluid exudes it shines no more.

When two pieces of lump sugar, agate, rock-crystal, or baked earthenware, are rubbed violently together, a vivid yellow light is produced, which is accompanied by heat, the cause of which must be the chemical changes which are induced among the ultimate particles of the bodies. When an air gun is discharged in the dark a vivid flash appears. Mr. Cavallo says, that if a discharge of an electric battery be made through a piece of loaf sugar strong enough to break and disperse it, every piece will emit a vivid light for a few seconds, after which they possess a peculiar smell and disagreeable taste.

CHAPTER IV.

On the Influence of Light upon Vegetables—its production by them—its Chemical and Magnetical effects, &c.

It is commonly observed that sun flowers and other plants always keep their discs towards the sun. In the morning they face the eastern sky; when the sun rises they attend him throughout his circuit; and in the evening look towards the point where he sets. On the morrow they again respect the orient heavens, and turn just in the same manner as on the preceding day. The whole process is a mystery, nor can any theory account for it.

Again there are flowers which, in the evening when the sun is set, shut up their cups; and in the following morning, when he has risen, open them again. This in a very striking manner reminds us of the sleep of animals; indeed there are some philosophers who are persuaded that plants as well as animals are subject to lassitude, and therefore require sleep; and have named this occurrence the vigils of plants. Others have attributed it to the effect of the calorific rays which are supposed to be emitted by the sun.

If a plant be shut up in a room, into which light is admitted through a small hole in the window shutter, and the pot in which it grows be placed out of the direction of the rays admitted, it will in a short time turn itself, and even grow downwards, that it may expose its leaves to the light. Should the room be made considerably warmer than the heat which is given by the light, yet the plant will turn itself from the fire to enjoy the sun shine. There is an evident connection between this fact and the phenomena of the discous flowers, and the cause of both is unknown. When plants are allowed to grow in the dark their leaves are white.

Some plants under certain circumstances emit light, not in the manner of phosphori, but in little faint flashes, succeeding each other with considerable velocity. This singular circumstance was first discovered in Sweden, by M. Haggern, Professor of Natural Philosophy. One evening, totally unsuspecting such an event, he observed a marygold emitting several small flashes. This appearance is common to all marygolds, but is considerably more effective in those of a dark yellow. The phenomenon is most evident when the atmosphere is very dry, but when it is very damp the flashes are never observed. These are not the only flowers which possess this curious property. M. Haggern, when he first observed it, supposed it to be the effects of phosphoric insects; but upon examination no such insects could be found. Since it has not been observed in moist weather, it is highly probable that electricity is the cause; but as the flash proceeds only from the petals of the flower, the professor concluded that the light was occasioned by the pollen, which, in flying off, is scattered on the petals.

The most prominent chemical effect of light is its action on plants. During the day they are observed to disengage large quantities of oxygen gas, which is referred to a decomposition effected in the organs of the plants through the immediate action of light. Carbonic acid and water form a very large part of vegetables; and these being decomposed, the carbon and hydrogen unite with the plant, whilst the oxygen is given out. The most effectual method of making the experiment is by enclosing a few leaves of the nasturtium in an inverted jar, which is filled with water. When this is exposed to the light bubbles of air will be emitted, which, upon examination, are found to be pure oxygen gas.

That light is the cause of this is beyond all doubt; for when vegetables are subjected to heat alone they produce no oxygen, therefore the hydrogen and carbon cannot become parts of them. The iron which they contain is the cause of their colour, and is produced by the action of light upon it, and this is the reason why plants, vegetating in the dark, are uniformly white.

Several of the metallic oxides, as the red oxide of lead and mercury, are powerfully acted upon by light, which seperates their oxygen, and reduces them. The muriate of silver is very proper for these experiments, for it becomes black. When this substance is exposed to the red division of the spectrum, which is formed by transmitting the sun's light through a triangular glass prism, it blackens very slowly; but in proportion as its situation approaches the violet division, it blackens more quickly; beyond the violet, and totally out of the calorific spectrum, it is found to blacken more speedily. From this singular phenomenon philosophers have beed led to suppose, that the sun emits another species of rays incapable of exciting the sensation of sight, but acting powerfully on oxygen gas, disengaging it from several combinations into which it has entered, and from this circumstance have named these rays de-oxydizing rays.

Plants and metallic oxides are not the only substances capable of being acted upon by the light of the sun. Several liquids, as nitric acid, are peculiarly subject to its influences. When exposed to the light of the sun, limpid nitric acid shortly becomes brown, the colour increasing in darkness according to the time of exposure. When nitric acid is exposed in this manner, in a small inverted jar, the upper part is found to contain oxygen, therefore the brownness is occasioned by the decomposition of a small quantity of the acid. Nitric acid consists of oxygen and nitrogen gases. When a portion of nitrogen is deprived of a part of its oxygen it becomes nitrous gas; which, mixing with the nitric acid, causes it to appear black or brown: the truth of this is easily proved by putting brown nitric acid into a retort, which is accommodated with the pneumatic apparatus; and, upon the application of a gentle heat, nitric gas will be disengaged.

Besides the colorific and de-oxydizing rays the sun emits another species, which, like the latter, are not apparent to the sight, but are dissimilar to them by exciting the sense of feeling. By means of a delicate air thermometer, Dr. Herschell found that in the violet region of the spectrum very little heat exists, and that, from thence to the red extremity, it gradually increases; but that its effects are most powerful when the thermometer is situated quite out of the colorific spectrum; from which it appears, that the calorific rays, as they have been called, are less refrangible than the other two. There is, however, much suspicion, that the calorific and de-oxydizing rays are very similar to the colorific. This will appear very probable when it is considered that light is only a peculiar state of matter, and that a small alteration in that state may cause effects widely differing from each other.

Some years ago it was observed by Dr. Morichini, in Italy, that there was some connection between light and magnetism; for he discovered that light had the remarkable property of conferring magnetism upon iron, so that needles, suspended in the violet ray of light, shortly became magnetic, and that they ranged themselves in the magnetic meridian. Subsequent discovery has shown that the property is not exclusively confined to the violet ray, but extends downward towards the other extremity of the spectrum, in a decreasing proportion, which raises an evident suspicion that the power is greatest beyond the violet extremity. Should this supposition be just, it would afford a powerful argument that magnetism and electricity are caused by the intervention of one power.

PART THE SECOND.

ON REFLECTION.

CHAPTER I.

On the Cause of Reflection.

The reflection of light is a fact which has been known from the earliest period with which we are acquainted. In the writings of Moses, which are supposed to be the most ancient in existence, mirrors or looking-glasses are mentioned. Homer frequently says that the armour of his heroes reflected the light, and the Mexicans and Peruvians had polished mirrors among them when the Spaniards discovered them. But long before this period, e'er furnaces were constructed, or the art of polishing metals was invented, natural phenomena must have informed the observer of the curious fact. If it be possible to suppose the early inhabitants of the world to have been inattentive to this at every other time we are certain the beauty of a setting sun, reflected on an eastern lake, must have caught the eye and fixed the attention of the most careless. Hypotheses, in which mankind so naturally indulge, were no doubt invented by them to account for the appearance, but the lapse of ages has buried them in oblivion.

Most of the ancient philosophers of Greece believed that light was reflected by actually impinging on the surfaces of bodies. The falsity of this doctrine has long ago been proved. For when metallic surfaces are polished, their greater eminences are worn down; but the most perfectly polished surface is comparatively rough, since the powder, whether tripoli putty, or sand, can do nothing more than scratch the surface in all directions. The protuberances occasioned by this operation must be great when compared with the particles of light, and therefore there could be no regular reflection. In the passage of light out of glass into air, there is a stronger reflection than out of air into glass. Now it cannot be supposed that air contains more solid particles than glass. If the air be drawn from behind the glass, the reflection becomes stronger, and it would be absurd to believe that vacuum contains more solid particles than a piece of glass.

Sir Isaac Newton was the first who demonstrated the falsity of this doctrine, and his reasoning was conclusive. To account for this most singular phenomenon, he invented his hypothesis "Of the fits of easy transmission and reflection," which is perhaps the most curious of his suppositions. Suppose the particles of light to move in an ether of such elasticity, that the vibrations occasioned by that motion may move with greater velocity than the light itself, these vibrations, striking on any solid substance, quickly cause its particles to assume a similar motion. Now if, when the particles of light arrive, the vibrations of the body conspire with their motion, they are disposed to be transmitted; but should the vibrating particles be moving in a contrary direction to the particles of light, they are disposed to be reflected. And if the particles of the body are not in a fit of easy transmission, every ray of light will be united in one; so that when they have arrived at the opposite side, the rays of one colour shall be in a fit of easy transmission, and those of another in a fit of easy reflection.

When it is necessary to offer an objection to the opinion of Newton, it should be done with caution, and humble deference to his opinion. This seems the more important now modern discoveries have shown in how few cases he erred. The author is not destitute of this feeling; it is impossible to possess a more reverential regard for any man, than is felt by every student who is aiming at truth in philosophical investigation, towards our immortal (with patriotism I speak it) master and countryman. But the supposition of such an elastic medium, as is required for the explanation of reflection by this doctrine, is perhaps gratuitous, for there is no evidence that such a medium or agent exists. Is it possible that reflection is accomplished by so complex a combination of causes, when nature always performs its operations in the easiest ways? This certainly appears an unnatural method of accounting for so simple a phenomenon. Besides, what does this hypothesis explain? The fits which Newton speaks of do not in the least elucidate the matter. Suppose a particle in a fit of easy reflection, or that its motion is acting contrary to the motion of light, how is it that the particles of light incident upon it can be reflected? Is it violently driven back? This must be the cause. But if the particles be driven back by the impulse of the particles of the vibrating body, it must lose a portion of its velocity. But it is a fact that the velocity of light, whether direct or reflected, is the same; for this is proved by observations on Jupiter's satellites, and the aberration of the fixed stars.

Both before and after Sir Isaac many believed that reflection was occasioned by a repulsive medium evenly spread over the surface of bodies, and acting at right angles on the surfaces. Now it is well known that there is a repulsive force spread over the surface of all bodies. The extreme velocity of light enables it to penetrate for a short distance into the repulsive medium; but meeting with a resistance, increasing as it proceeds, which by its superior energy overcomes it, it is repelled and quits the medium with the same velocity as it entered.

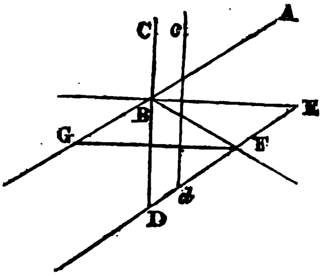
This hypothesis accounts in a very perspicuous manner for the reflection of light from the surfaces of opaque bodies; but when light is reflected from the second surface of transparent substances, as in prisms, &c., the case requires to be viewed in another manner. The cause of this is that attraction by which, if light passed out of a transparent substance, it would be refracted. This will appear evident when it is considered, that if light be transmitted through glass into air, at as great an obliquity as is possible, should that obliquity be increased instead of being transmitted, the light will be totally reflected. The reason of this is, that when the light has been refracted at as great an obliquity as possible, and that obliquity be increased, the attractive force of the glass becomes too powerful, and reflection is the necessary consequence. When light passes out of one medium into another, the reflection should be stronger, in proportion as the refractive power of the one medium exceeds the refractive power of the other. This is the necessary consequence of this hypothesis. Now let the truth of it be examined by experiment. When light passes out of glass into a vacuum, the reflection is as strong as possible. When, under similar circumstances, it passes into air, it is much stronger than it would be if it should pass from glass into water, but considerably less than when it passes into a vacuum. When a fluid is used, whose refractive power is equal to the refractive power of the glass employed, no reflection whatever ensues; and those substances which are possessed of the greatest refractive power, are likewise possessed of the greatest reflective.

The reflection of light may therefore be divided into two cases: 1st, That caused by a repulsive force, which exerts itself at very small distances from the surface of any opaque matter, and, being unable to penetrate to the substance itself, is violently repelled, with a velocity similar to that with which it entered the repulsive medium. The unevenness of the surfaces of polished substances will form no obstacle to this hypothesis, as it does to that which considers reflection produced by actual impinging. To make use of a simile to illustrate this: Bodies, projected from the surface of the earth, are not in any sensible manner affected by the attraction of the highest mountains on the surface, because their attraction is so small compared with the whole mass. In like manner, the particles of light are not affected by the repulsion of the extremely small protuberances on well polished surfaces, because their repulsion is so very small, compared with the repulsion of the whole; and therefore they are all reflected with uniformity.

The second case is when the reflection of the particles of light is caused by the attractive force exerted by the medium through which the particles have passed, and is apparent at the second surface; the truth of which is shown at large above.

CHAPTER II.

On the Laws of Reflection.



Lemma. Let any particle A of matter move from A in the direction A B G with a determinate velocity, and let its motion be stopped by the repulsive influence of the plane E D, which influence acts in lines, parallel to E B, that is, perpendicular to C D. Then will the angle A B E be equal to the angle E B F.

Let A B represent the velocity of the moving particle, A and B E the force exerted by the particle B, but any line parallel to A B will represent the same force that A B itself does. Therefore, when the particle of matter has arrived in B, let its force and direction of motion be represented by B G. Now when the particle has arrived in B, the force E B (which has been increasing during the passage of the particle through the repulsive medium,) becomes so great as to preclude the possibility of its procedure in the direction A G. In the point B therefore there are two acting forces, B E and B G, whose force and direction are supposed to be the lines B E, B G. Complete the figure E G, then the path described by the particles will be B F.* But the angle G B F is bisected by C D, for E B is parallel to G F, and C D is perpendicular to both. Therefore the angles, A B C and F B D are equal, as are the angles E B C and E B D. That is, the angle A B E is equal to the angle E B F. Therefore if any particle &c. Q. E. D.

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* Principia New., Vol. I., Leges Motus.

Corol. 1. When the particle of matter moves in the direction E B, or perpendicular to the reflecting surface, its force is destroyed in B, and an equal force, tending in the opposite direction B E, is impressed upon it.

The angle A B E is called the angle of Incidence, and the angle E B F, the angle of Reflection.

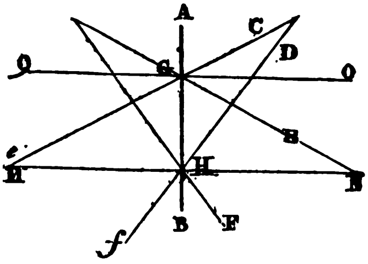
The preceding proposition may be more familiarly demonstrated in the following manner: The moment that the particle A has arrived within the sphere of Repulsion of the plane C D its motion is retarded, and becomes more so as it advances. Let *c d* represent the greatest efficient distance of this repulsive force when it has arrived at such a depth in the repulsive medium that the impetus of its velocity is unable to impel it to penetrate further; the direction of its motion is necessarily changed in B to the other side of E B, and its path is in some line as B F.

The reason of this change of direction is evident; for if the particle, when arrived at B, were to return in the line B A, the velocity which it posseses in B must be entirely taken from it, and a new projectile force be given it in a contrary direction, which can but happen in one case, or when the particle moves perpendicularly to the reflecting medium. For as the repulsive force acts only in directions perpendicular to the surface of the reflecting medium, *c d,* when the particle moves in a direction parallel to the surface of that medium, no reflection can ensue. At all intermediate angles, the particle has to overcome the resisting force exerted against it; and it is plain that the nearer the direction of the motion of the particle is to the direction of the force, the force exerted upon it, after it has overcome the motion of the particle, must be so much the more vehement. But as this resisting force is spread equally over the whole surface, its action must be equal in all parts of that surface; therefore the particle cannot be repelled in a direction more parallel to the direction of the repulsive force; for that would require the exertion of a greater force than that which resisted its entrance into the medium, which is against the hypothesis; neither can it be repelled in a direction more parallel to the superficies of the plane, for, to effect this, it would require the exertion of a less force than resisted the particle at its entrance, which is likewise against the hypothesis.

Prop. I. Theorem. When a ray of light falls uonp a reflective surface, and is reflected by it, the angle of Incidence is in all cases equal to the angle of Reflection.

From the preceding Lemma this will appear evident; for what happens to one particle of matter must happen to a succession of such particles, which constitute a ray. In experiment the truth of this Theorem is displayed; and indeed it was long known as a fact, before the demonstration could be furnished, being discovered by the disciples of Plato.

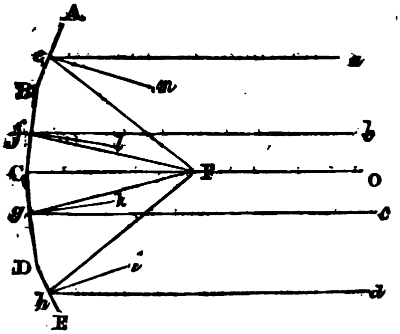
Prop. II. Theorem. Any two rays of light, after reflection from a plane surface, contain the same angle which they did before such reflection occurred.



Let AB be the plane surface, C *e* and D *f* two rays of light, which are reflected by the plane in the points G and H, in the directions GE and HF. By Prop. I. the angles CGO and DHN are equal to the angles CGE and NHF, respectively. But the angles *e*GH, *f*HB, are equal to the angles AGC and AHD respectively. (Euc. Prop. XV. Book 1.) Therefore the angles CGE and NHF are equal to the angles QG*e* and MH*f*. Therefore the inclination of the reflected rays GE and HF is the same as *e*G to *f*H, consequently, the angle contained between them is equal to the angle contained between *e*C and *f*D. Therefore, any two rays, &c. Q. E. D.

Prop. III. Theorem. When parallel rays of light fall upon a concave surface, AE, and are reflected by it, they will converge and eventually meet in a point as F, where they will cross each other.

Let AE be a concave surface, and composed of an infinite number of infinitely small planes, inclined to each other. Let AB, BC, CD, DE, represent any of these planes; and let the parallel rays, *a b c d*, fall upon these in-



clined plane surfaces, in the points *e*, *f*, *g*, *h*. Let *e m*, *f l*, *g k*, *h i*, be lines perpendicular to the inclined planes; make the angle *a e m* equal to the angle *m e* F, the angle *b f l* equal to *l f* F, and so with the others, which will respectively represent the angles of incidence and reflection.

Now the angle *m e* F being greater than the angle *b f* F, the line *e* F must cross the line *f* F in some point which shall be F. The ray O C, falling perpendicularly upon the repulsive medium, is reflected back in the same direction as it entered, and it passes through F. In like manner, as the rays *a e*, and *b f*, are reflected into F, so are *c g* and *d h* reflected to the same point.

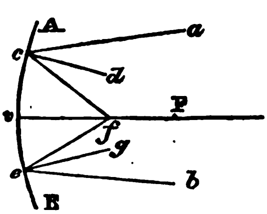
As the surfaces A B, B C, C D, D E are supposed to be infinitely small and in infinite number, it is plain that by their inclination they will form a concave superficies of a curvilinear form; and it is likewise evident, by inspection, that the direction of any reflected ray may be easily found; for if a perpendicular be drawn to the tangent, drawn from the point where the ray is reflected from, and an angle be taken equal to the angle formed by the incident ray and the perpendicular, the reflected ray will follow the path of the line of that angle; for if a curve be drawn, touching the plane lines A B, B C, C D, D E, in the points *e f*, *g h*, those plane lines will become tangents to the curve in those points.

Schol. The point F has been called the focus, from a Latin substantive signifying fire-place or hearth; for this reason, that a concave mirror being exposed to the sun's rays converges them into one point, and there causes so great a degree of heat that any inflammable substance may be burned.

Prop. IV. Theorem. When rays of light, diverging from the natural focus of any concave surface, fall upon that surface, they are reflected by its parallel to the axis of that concave surface.

This proposition is the converse of the preceding, and is easily deduced from it.

Prop. V. Theorem. When converging rays of light fall upon a concave surface they will converge still more, and eventually meet in a focus nearer to that surface than they would have done had they been parallel.

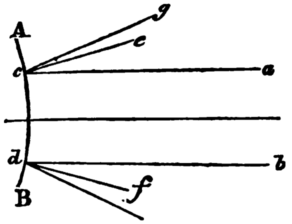


Let A E be supposed to be constituted of an indefinite number of infinitely small planes, and let the rays *a c*, *b e*, converging at some distant point, fall upon it in the points *c* and *e*; now the angle *a c d* will be larger than it would have been had the rays fallen parallel to the axis; therefore the angle *d c f* will be greater; consequently, the angles *f c e* and *f e c* will be less; that is, *c f* and *e f* are less than before; but they intersect each other, and therefore the point of intersection will be nearer the vertex *v* than F is, therefore the focus is *f*.

Corol. When rays of light, *f c*, *f e*, diverging from a point nearer the concave surface than the natural focus, fall upon that surface, they are reflected diverging, but less than before reflection.

Prop. VI. Theorem. When parallel rays of light fall upon a convex surface, and are reflected by it, they diverge.

Let *a c* and *b d* be any two incident rays, *c e* and *d f* perpendiculars to the direction of the curve; then as the incident ray *a c* forms the angle *a c e*, with the perpendicular, the reflected ray *c g*, will make the angle of refraction equal to it. But as the incident ray falls nearer the axis than its proper perpendicular, the reflected ray will diverge. The same happens with the ray *b d*. The ray which falls perpendicularly on the surface will be reflected back in the path in which it came.



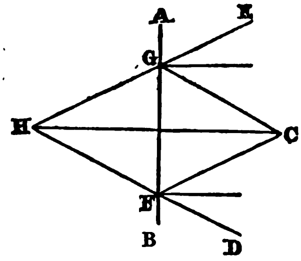
Corol. 1. When diverging rays of light fall upon a convex surface, they are rendered parallel, diverging or converging.

CHAPTER III.

On finding the foci of the plane, and different Curvilinear Mirrors.

The determination of the focus of any mirror, or finding the point where any two of the incident rays coincide, meet, and cross one another, may be performed by a general fluxionary equation, or in the sequent manner.

Prop. I. Theorem. When any two rays of light fall diverging upon a plane mirror, when reflected, their focus will be at an equal distance behind the surface of the mirror, as the radiant point is before it. Let C G, C F be any two divergent rays of light, which fall upon a plane mirror, A B, and are reflected in the path of the lines G E, F D, their imaginary focus H will be at an equal distance behind the surface.



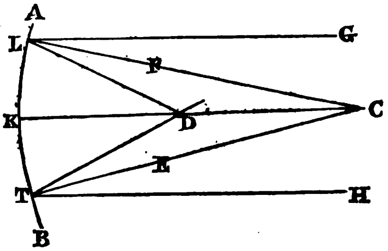
Since the angles D F A and F G B are equal, their supplements H G F and H F G are likewise similar in the triangle F H G, and C F G, the base F G is common, and the angle C G F = H G F and C F G = H F G, therefore the side H G = G C, and H F equal F C, and the line H C is bisected by A B. Therefore when any two rays of light, &c. Q. E. D.

Prop. II. When any two rays of light, which converge, fall upon a plane mirror, and are reflected by it, their focus will be at an equal distance before the surface of that mirror, as their imaginary focus is behind it.

Let E G and D E (preceding fig.) be the two convergent rays, falling upon the plane mirror A B, which are reflected by it, their focus C will be at an equal distance before the surface of the mirror A B, as their imaginary focus is behind it.

For the convergent rays F G D E being reflected, join in one focus C, and H is the imaginary focus. The line H C is bisected by A B. (See Prop. I.) Therefore when any two rays, &c. Q. E. D.

Prop. III. Theorem. When parallel rays of light fall upon a concave spherical mirror, the focus of the reflected rays is at the distance of half the radius from that mirror.

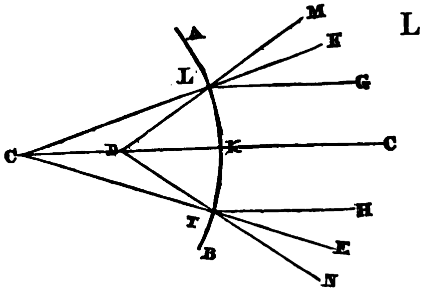


Let G L, H T, be two rays of light, incident upon the concave mirror A B, in the points L, T, to these two points let fall the perpendiculars L F, T E; the angles G L F = F L D, and H T E = E T D; then the focus D, of the reflected rays, will be distant from K half the length of the line K C.

In the triangle C L D the angles L and C are equal to each other, and therefore the sides L D and D C are equal. In the triangles T C D the angles at T and C are equal, and therefore D C and D T are equal. Suppose the arc K L, or K T, to become infinitely small, then the triangles L D C, or T D C, will vanish, and K D equals D C.

Schol. From this proposition it appears that spherical mirrors can never collect incident rays into one focus; for suppose the arc A B to become a semicircle, and therefore the mirror a hemisphere, the lines L D would have become greater than D C, for $LD^2 = DC^2 + CL^2$. But this subject will be again resumed under aberration.

Prop. IV. Theorem. When parallel rays of light fall upon a convex spherical mirror, the virtual focus of the reflected rays is at the distance of half the radius from that mirror.

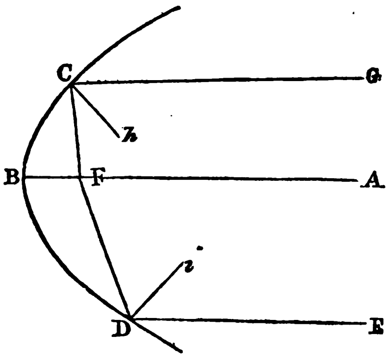


Let G L, H T, be two rays of light, incident upon the concave mirror, A B, in the points L T, to these two points let the radii C L, C T be drawn; which will be perpendicular to a tangent drawn to the curve in those points.

Now as the angle H T E = E T N and M L F = F L G, therefore the two angles, M L G, and H T N are bisected by the radii C L, C T, produced to F and E, the angles L C D and C L D = M L F; and the sides C D, D L, are equal to each other, in the same manner the sides D E, D T are proved equal to each other. Let the arcs become infinitely small, and C D = D K. Q. E. D.

These are the principal propositions for spherical surfaces, when parallel rays are under consideration; but when converging or diverging rays are concerned, the focus is moveable just according to the position of the radiant point, and it must be determined in a similar manner to these given lines.

Prop. V. Theorem. When parallel rays fall upon a concave parabolical surface, they are reflected so that every ray shall meet every other accurately in the focus of that parabola.



Let G C, E D be any two parallel rays, falling upon the parabolic mirror, D B C. Now by the properties of this curve, the angle G C F, made by a line parallel to the axis and another line, drawn from the point C, where that parallel line touches the curve, to the focus, is bisected by a line drawn perpendicularly to a tangent to that point. Let the angle G C *h* be the angle of incidence, then *h* C F will be the angle of reflection; the same reasoning being employed to the ray E D, it will appear that it crosses the other in F. Therefore when parallel rays fall upon a concave, &c. Q. E. D.

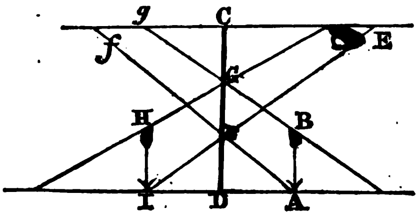
Schol. In this manner the reflective properties of other curves are determined from their geometrical properties, as in the Ellipse and Hyperbola; for since lines drawn from the foci to any other point make equal angles, with a tangent of that point, therefore if incident rays proceed from one of the foci, the reflected rays proceed to the other.

CHAPTER IV.

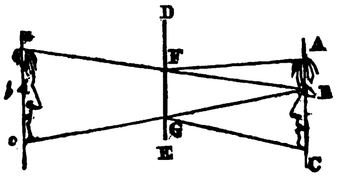
Of the appearances under which bodies are seen, when their Images are viewed, after Reflection, from Plane, Convex, Concave, and Cylindrical Mirrors.

If the reflected image of any object be viewed, each point of it appears situated in a right line drawn perpendicularly to the surface of the mirror from the point which corresponds to it in the object. A very little consideration will elucidate this fact; for it must appear, that the place of the object, when referred to the surface of the mirror, will appear somewhere in a line which is perpendicular to the tangent at that point, but as the tangent at any point of the surface coincides with that point, any line which is perpendicular to the one must be perpendicular to the other; and therefore if the reflected image of any object be viewed in any mirror, each point of it will appear situated in a right line drawn perpendicularly to the surface of that mirror, in that point, to the corresponding point of the object.

When any object is viewed in a plane mirror, the image appears at the same distance behind the mirror as that object is before it. "The illusion is so complete that domestic animals, when viewing themselves for the first time in a plane mirror, have their passions strongly excited." Birds are extremely susceptible of this; for if a large looking-glass be placed before a cock, it is almost a certainty that he will commence a combat, and very speedily demolish the cause of his wrath; the fury which this animal shows is uncommonly entertaining. The reason of this illusion is, that the rays proceeding, after reflection, to the eye, have the same inclination to each other as they had before such reflection. (Prop. II.) The object A B sends forth two rays, A G and B F, which would move converging to the points *g* and *f*, if they were not reflected by the plane mirror CD, in the direction GEFE; where they are viewed by the eye, E. Now these two rays, in moving towards E, have the same inclination as if they were moving towards *g* and *f*. (Prop. II., Chap. II.) And as the point I appears situate in the line A C I, the angle A F I will be bisected by the surface of the mirror, and therefore I D is equal to A D.



Objects viewed in a plane mirror by themselves appear but half their true size. Let A B C be the figure of a man observing his image in a plane mirror, D E. The image *a b* will appear at the same distance behind the mirror as the object is before it; and therefore the angle *a* B *c* will be bisected by the mirror in F G, but if *a* B and *c* B are besected, *a c* will be equal to twice F G; and therefore the length of the image will be but one half the length of the object. And in the same manner, the breadth, and all other diameters of the image, are proved to be but half the extent of those of the object, and this is the reason



why a man may see his whole image in a looking-glass, which is but half his length and breadth.

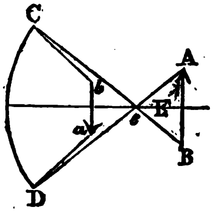
By combining plane mirrors an object may be seen multiplied to any extent, when the mirrors are only two in number, and are situated at right angles to each other, the object appears multiplied four times, twice by single, and twice by double reflection; when the mirrors are arranged parallel to each other, the object being placed at one extremity and the eye at the other, the object will appear infinitely multiplied by the reiterated reflection, from one surface to another; the images gradually becoming more and more indistinct as their distance increases.

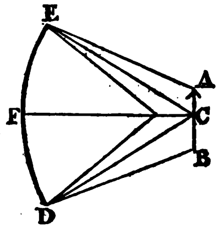
In convex mirrors, objects appear in their natural positions considerably magnified, and nearer the reflecting surface of the mirror. They appear in their natural posture since the reflecting rays do not intersect each other, for they diverge. They must appear less since the angle under which they are seen is considerably less, through the diverging of the reflected rays; and for the same reason they appear nearer the surface, as the virtual focus is nearer to it.

When an object is placed nearer to the surface of a concave spherical mirror than the natural focus, the rays must necessarily diverge after reflection; but in a less degree than before such reflection occurred; the image is therefore magnified, and is formed at a greater or less distance from the surface of the mirror, according as the distance between the radiant point and the focus of parallel rays, or the natural focus, is less or greater; for as the power of the mirror, to make the rays converge, is less effectual, in proportion as those rays have diverged more before reflection, and as the rays will diverge more the nearer they are to the reflecting surface, therefore, as the object approaches that surface, the focus formed by the converging power of that mirror must be at a greater distance. There is one point in which if the object shall be situated no focus whatever can be formed; for if it be placed so that it touches the mirror, the power of the mirror will be insufficient to cause convergency, and therefore no focus can be formed.

In spherical mirrors when the object is placed in the focus of parallel rays, the reflected rays become parallel, and the image appears magnified, and near to the surface of the mirror. It appears near to the surface, because the deception, arising from the magnitude and brightness conjointly, influence the mind to the belief that the image is nearer than it truly is; for, by the theory, the distance from the reflected surface should be infinite; but in the common objects which we view, we usually assume the size and brightness of objects as the criterion of admeasurement of their distance. When a distant rock is perceived, its distance cannot be judged with any degree of accuracy, but a guess is substituted. If it appear small, and its extremities ill defined, a supposition that it is very distant is the natural consequence; but if it shall appear well defined in all its parts, and at the same time answer the expectations formed of its magnitude, it is supposed very near. This is always found to be the case; and when in a concave mirror an object appears bright, magnified, and distinct, a supposition of its nearness is naturally entertained.

When the situation of an object is beyond the focus of parallel rays in any concave mirror, the focus will lie between that focus and the surface of the mirror, and the image will be formed nearer the surface of the mirror, minified and in an inverted position, as in the figure, where A B is the object, A D and B C two rays proceding from its two extremities, which are reflected in the direction C *b* D *a;* it is evident that the focus is nearer than the focus of parallel rays, and that the image is inverted, and necessarily less; for the diverging rays A D and B C cross each other in *e* before they are reflected. If the object should be placed in the centre of the concavity of the mirror, then all the diverging rays issuing from it will fall perpendicularly upon the surface of the repulsive medium; which, acting only in that direction, must necessarily repel them back in the direction in which they came; and therefore the focus of the image will coincide with the object, but the image itself will be inverted with respect to the object. For if A B represent the object situated in the centre of concavity C, of the spherical mirror D E, the ray C F, which falls perpendicularly upon the reflective medium, is reflected back into C. The ray A E, issuing from A, and falling upon the mirror at E, is reflected in the direction E B. If C E be drawn perpendicularly to the surface of the mirror, then A E C is the angle of reflection, and C E B the angle of incidence; therefore A is reflected into B. In the same manner it





may be shown that B is reflected into A; and therefore all the intermediate points between A and C are reflected into others, situated at equal distances from C, on the side B C and the converse. And, therefore, the image is inverted with respect to the object A B.

When the eye is placed between the reflecting surface and the image, the object is seen beyond the surface; its extremities exceedingly confused, and the image magnified. When the eye recedes the image is nearer the surface; and as the eye retreats the image appears nearer and nearer to the surface.

If any one looks into a large concave mirror, whose distance from him is greater than its focal distance, there will appear between himself and the mirror a minified representation of himself suspended in the air, and inverted. This deception is astonishingly effectual, and if the object be placed on his head, an ignorant observer would with difficulty be brought to a belief that the pendulous image is not tangible. The success of this experiment increases with the diameter of the mirror. As this image can be seen but in one position, and by one person at the same time, there has been considerable suspicion excited that this experiment was used on a large scale by Pagan priests and priestesses; in such cases as at the cave of Trophonius, the Temple of Delphi, and other places where mysteries were common. That the ancients were well acquainted with this property of the concave mirror will be shortly proved by their own evidence; and the mysterious and miraculous exhibitions displayed at some of the ancient temples, shows the supposition in a most important light.

That the image in all these cases exhibited is matter, no one can doubt, who believes light to be a material nature; the only difference between it and any other matter is, that the particles which compose it, not being held together by an attractive force, repel each other. As these particles repel each other, it follows that they are not tangible; for although the image formed by one collection of particles endures but for an extremely short period, (these particles being constantly succeeded by others which cause the image to appear permanent,) yet as they are infinitely small, their velocity will not in the least render them cognizable to the sense of touch. But the image is acted upon by external forces exactly in the same manner as the object itself would be, supposing all its particles should repel each other. Now if each and all of the particles of the object repelled each other, there would be an attempt in the whole body, and in every particle, to be projected in right lines diverging from one another's influence, which is the case in the image. If any obstacle be presented to the body in such a state as that supposed, which should be impermeable to the effluent particles, they would be repelled according to the laws of the percussion of perfectly elastic bodies; which is likewise the case with the particles of the image. In whatever situation the repellent particles of the body shall be considered, the result of the experiment on the particles of the image in similar circumstances is similar, and therefore the pendulous images in the air afford evident proof of the truth of the general Lemma, concerning the ultimate particles of matter—and to the general proposition on the nature of light—demonstrating that impenetrability *is not necessary* either to matter or its extension.

Cylindrical mirrors are of very little use in the construction of optical instruments, but are ground by opticians merely for the purposes of amusement. When any one views himself in one of these, if the direction of the axis of its concavity be perpendicular to the horizon, his visage will be uncommonly distorted; diminished in breadth, but in length continuing as usual. The drollery of the figure strongly reminds the observer of Homer's description of Thersites, Book II. ver. 219, φοξὸς ἔην κεφαλὴν· Upon turning the mirror a quadrant, the opposite extreme takes place; the image much resembling a piece of paper with two lines drawn on it, one in black ink the other in red. The eyes are elongated so as to resemble the black line, and the lips the red; added to this, the extraordinary breadth of countenance, and the ungovernable obstinacy of the image, is very laughable; for if the mouth be opened "wide as some huge Leviathan," still the longilateral one keeps his shut; and only a white stroke of extreme tenuity is seen to run parallel along the centre of the red one, which is caused by the teeth. If the mirror be held close to the face of the observer, (its axis being verticle,) and the finger be put to the right side of the nose, the image will of course do the same. But "I removed the mirror a greater distance from my face, and then placed my finger in the same situation; the image then put his on the left side of his nose. I could contain no longer, but gave vent to my inclination by a loud fit of laughter. Unhappy being! for the image now opened his mouth to such an astonishing extent, and his long countenance seemed so dreadfully convulsed with some uncommon passion, that I willingly let the mirror fall to the ground, avowing that I would never look into another."

Anamorpheses are frequently used with these mirrors, and considerably heighten the amusement they afford. They are pictures drawn of a shape so distorted, that when they are presented before the cylindrical mirror, it rectifies them, and they assume a natural appearance.

CHAPTER V.

History of several Discoveries relative to the Reflection of Light.

The first mention made of reflection from polished metallic surfaces is in the Book of Exodus, ch. xxxviii. v. 8, where it is said, that the looking-glasses of the Israelitish women were made of brass. Callimachus, the Cyrenean, mentions the same fact in his hymn to Pallas, using the word ορεικαλκον, "She never looked into either a mirror of orichalcum or into water." Concerning the true meaning of the word orichalcum there has been much controversy; but the general opinion seems to be, that it was brass of a very dark hue. Some, from the etymology of the word, translate it, mountain brass; others, brass of a golden colour; and others, brass of a fiery colour; but nearly all consider it to be brass of some description. It therefore appears that brass was the first metal used for looking-glasses and it is very well fitted for that purpose, as it takes an excellent polish, and is not so liable to tarnish as any other metals.

In those ancient poems which pass under the name of Homer, frequent mention of this fact is made. These books are full of descriptions of the beauty of the shining armour of his heroes. The following description of the lance and breast-plate of his great hero, Achilles, is the most beautiful and explicit in the Iliad. (Book xxii. ver. 134.)

> ......ἀμρὶ δὲ χαλκὸς ἐλάμπετο εἴκελος αὐγῇ
> Ἢ πυρὸς αἰθομένοιο ἢ ἠελίου ἀνιόντος.

> The Pelian javlin in his better hand
> Shot trembling rays, which glittered o'er the land;
> And on his breast the beamy splendour shone,
> Like Jove's own lightning, or the rising sun.

Æsop, of fabulistic memory, mentions a particular description of reflection, viz., from fluid surfaces, which must have been frequently observed before his time: but there is in the place to which I allude a singular observation, the reason of which has already been explained. It is, That images reflected from plane surfaces appear as far behind that surface as the body itself is before it: the passage need not be mentioned at length, for every one has read the fable of the dog and his shadow.

Aristotle discovered the cause of twilight, supposing it to be occasioned by the reflection of the light of the sun from the atmosphere; he knew that a similar reflection prevents shadow from appearing totally black, and he taught, that rainbows, halos, &c., are occasioned by the reflection of light.

Euclid, of Alexandria, who lived about B. C. 180, wrote a work on Catoptrics, or the reflection of light, which is supposed to be lost, as the work which has his name affixed to it has not that elegance and accuracy which usually distinguishes the works of the compiler of the "Elements." Before his time, however, some one had discovered that the apparent place of any object seen in a plane mirror, is equal to the distance on a perpendicular, drawn at right angles, to the reflecting surface, where a reflected ray would meet that perpendicular; affording therefore a demonstration of the fact which Æsop, before him, had noticed.

Archimedes was the next author of any fame who made any discoveries concerning the reflection of light. His burning mirror is celebrated throughout the world. In modern times, many have treated it as a fable; but the united testimony of Lucian, Eustanthius, Zonares, and others, should have long ago settled the dispute. An ancient historian says, "When the fleet of Marcellus was within bow-shot, the old man Archimedes brought an hexagonal mirror, which he had previously prepared; at a proper distance from this he placed other smaller mirrors of the same kind, which moved in all directions on hinges, and which, when placed in the sun's rays, he directed on the Roman fleet, and reduced it to ashes." Eustathius, the Archbishop of Thessolonica, in his Commentary on Homer's Iliad, says, That Archimedes, by means of a reflecting mirror, burned a Roman fleet at the distance of a bow-shot. Zonares, the historian, in his "Annals," says, That Proclus, in imitation of what Archimedes had done at Syracuse, burned the fleet of Vittelion, at the siege of Constantinople; and that the engine employed was a reflecting mirror, consisting of twenty-four smaller ones; which, by directing the rays of the sun to one point, excited an intense heat; and this he did in imitation of Archimedes. Galen, the physician, who lived A. D. 130, says that Archimedes, by means of glasses, burned the ships of the Romans. The point was completely established by M. Buffon, who gave the best demonstration possible, by making a machine of this description, which was found equal to the effects assigned to that of Archimedes.

Aulus Gellius, in his book called "Noctes Atticæ," makes mention of mirrors, which inverted objects; these must have been concave mirrors, and if it was known that they inverted, it is unlikely that their magnifying power should be unknown. That this was the case will be shown, under the history of Optical Instruments.

Claudius Ptolemy, who lived about A. D. 130, wrote a Treatise on Catoptrics, Dioptrics, &c., which it is said is yet extant in manuscript.

John Baptista Porta, whose name is eminent among the first writers on optics, supposes the burning mirrors employed by the ancients were parabolic surfaces; this curve has been shown to collect the rays into one point in its focus, and there burn fiercely. Therefore, if a part of the parobolic surface were cut off as far as the focus, it would be converted into a burning mirror.

The next particular phenomenon which engaged public attention was seeing images in the air. It was generally believed that it was possible to see an image reflected from mirrors, without seeing the object or the mirror. And whilst it went for fact that friar Bacon had walked in the air, from the top of a church-steeple to that of another, the literati resolved the miraculous appearance by supposing it to be effected by a particular kind of mirror, reflecting his image as he walked, on the ground. Lord Bacon relates this story, and gives ihs assent to the truth of the eclaircissement.

Kircher, in his voluminous writings, shows several methods of producing these effects, but they are mere illusions, as in all similar cases it is necessary to see the mirror; however, it may be here observed, that this effect may be produced in the greatest perfection and with remarkable success, by throwing the image on a body of dense smoke, or other vapour. Kircher wrote several works on optics, as "Ars magna Lucis et Umbræ;" "Primitiæ Gnomonicæ Catioptricœ."

The Honourable R. Boyle made a great number of optical experiments on different subjects. He determined that white substances reflect more light than those of any other colour, and discovered the nature of both blackness and whiteness; showing that white bodies reflect all their incident light, and black ones absorb it; demonstrating that light, after its incidence on black bodies, and subsequent extinction by them, becomes heat. He made many experiments on the reflection and transmission of light, with a view to determine the nature of the colour of bodies; and reasoned upon the nature of the colour of bubbles of soap and water, or turpentine.

Dr. Hook, who has given to the world a new Theory of Light, exhibited, in its greatest perfection, the famous soap bubble, to the Royal Society. He showed that the plates of different substances are endowed with particular colours. Dr. Hook wrote several optical works.

It is more than a century ago since M. Bouguer read an article in the Memoirs of the French Academy, by M. Mairan, which treated on the relative proportion of the light of the sun at the two solstices. Struck with the novelty and curiosity of the subject, he commenced a course of experiments on the actual admeasurement of reflected and incident rays, and was more successful in his conclusions than any of his predecessors. Under these circumstances, he published the result in his

"Essai d'Optique," and shortly after commenced a much larger work; but death, who spares neither the learned or illiterate, cut him off before his successful labours were closed; and at his particular desire they were completed and published under the care of De la Caille, with the title "Traité d'Optique," which certainly is the most instructive work ever written on Catoptrics.

Sir Isaac Newton did not publish his great work on Optics till 1701, for he had been vehemently opposed by Dr. Hook; and as his hypotheses were novel, he did not think it right to publish them till Hook's decease. After his death they were printed, and may almost be said to have created the science of optics. The foundations of the science being thus laid, philosophers turned their attention to its several divisions. Mr. Melville wrote on the heating effect of light, and Mr. Grey made several curious experiments, as the Ærial Specula, &c. Since the time of Newton, the experiments and discoveries on reflected light are very numerous; but they are chiefly connected with other parts of the science, and need explanations from other doctrines; such as Dr. Brewster's experiments on the blue colour of the sky, the polarisation of reflected light, &c., which shall be recited in their proper places.

PART THE THIRD.

ON REFRACTION.

CHAPTER I.

On the Cause of Refraction.

Refraction is a part of Optics which, perhaps, was discovered quite as early as Reflection; but the common phenomena of it are of so much less frequent occurrence than catoptrical phenomena, that many learned men have doubted whether it was known before the time of Pythagoras. But the shepherd, the traveller, and the husbandman, must all have noticed the appearance of a stick, when half immersed in water; for this has been observed time out of mind; and perhaps the explanation of this phenomenon gave birth to the whole science.

The ancients were not long in discovering the cause of refraction. Claudius Ptolemy, who lived under the reign of Marcus Aurelias, speaks of it as though it was no new discovery. Althazen regards it in a similar manner; both attributing it to the attraction of the refracting medium.

Let any particle of light *a*, emanating from a point

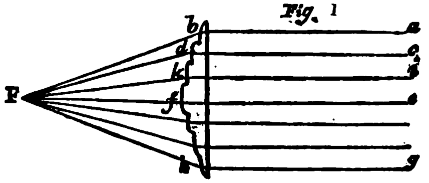


Fig. 1

a, be incident on a medium *b h*, whose density exceeds that of the circumambient air. Let one of its sides be plane, and the other composed of several qradrilateral figures, *b*, *d*, *k*, *f*, each larger than the one above it, and consequently projecting more towards F. Now it is supposed that the particle *a* falls upon the plane side of *b* perpendicularly, therefore its velocity is accelerated by the action of the attractive force of B, and it passes on to the other extremity of the medium; here it would pass out in the direction of *a b*, (fig. 2) but as soon as it has arrived in *b*, and passed beyond the attractive influence of *b*, the whole force *d e* is exerted upon it in an endeavour to draw it down to itself; but the velocity which *a* possessed before that influence was exerted still continues, and therefore *a* is only bent from its course into the direction *b f*; and this is wholly effected by the attractive influence of *d e*: in the same manner, any other ray—*c d*, is refracted by the attraction of the particle *g*, below it, and (Fig. 1) all of the rays *a*, *c*, *i*, *g*, are refracted exactly in the same manner. With regard to the ray *e f*, as that is supposed to fall perpendicularly upon both sides of the medium, no alteration in its direction can take place, as it is equally attracted on both sides, and therefore the change of the velocity of *a* is all that can happen.

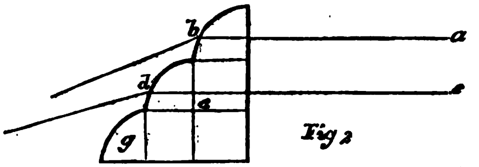


Fig 2

The influence which the attraction of the whole mass of the medium exerts upon the passing particle may easily be understood; for when a particle of light passes through any medium, its motions are influenced only by those particles which are immediately adjacent to it, and by none others. For the attractive or repulsive forces of those particles, between which and the particles of light there exist other particles of matter, are neutralized.

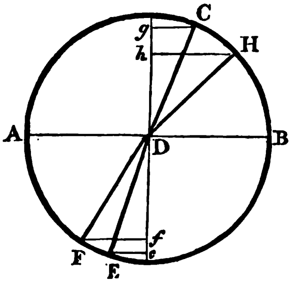
The angle of incidence is the angle which a perpendicular, drawn to that point on which a ray of light is incident, makes with that ray.

The angle of refraction is the angle which a ray of light, after refraction, makes with a perpendicular drawn to that point.

CHAPTER II.

The Laws of Refraction.

Prob. I. Theorem. When any two rays of light fall upon the same medium at different angles of incidence, the sines of the angles of refraction will be to the sines of their respective angles of incidence in the same proportion.

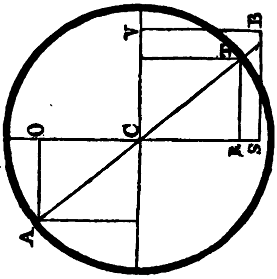


Let A B be the surface of a medium of greater density than its superincumbent one, A B C; C D and H D two incident rays; D E and D F their respective refracted rays; *g* C, *h* H, the sines of the angles of incidence; *e* E, *f* F the sines of the angles of refraction; now *e* E will be to *g* C as *f* F is to *h* H.

For, as the refractive medium is the same throughout, the influence of any one particle will be equal to the influence of any other particle; and therefore if *h* H, the sine of the angle of incidence, be twice, thrice, or four times the sine of *g* C, it follows that a particle moving in the direction H C, shall experience twice, thrice, or four times the force of a particle moving in the path C D, and therefore it shall be refracted twice, thrice, or four times as much as that particle; that is, *f* F, or the sine of its angle of refraction, shall be twice, thrice, or four times E *e*. Therefore, when any two rays, &c. Q. E. D.

Prop. II. Theorem. When a particle of light passes obliquely in or out of any medium, the sine of the angle of incidence is to the sine of the angle of refraction in the constant ratio of the velocity of refracted to that of the incident light.

The line C B cuts the circle A V T in T described with the radius C A: draw from the points B and T the lines B S and T R perpendicular to C S. But the triangles C B S, C T R are similar; therefore B C is to T C or C A as B S to T R; which lines, therefore, by reason of B C and C A being constant, will always be in the same ratio, whatever the angle of incidence be, T R is the sine of the angle of refraction T C R, and B S = C O = A O, which is the sine of the angle of incidence A C O, between which sines there is a constant ratio. These sines are inversely as the velocity of incidence to the velocity of refracted light. Therefore, when a particle of light passes in or out, &c. Q. E D.

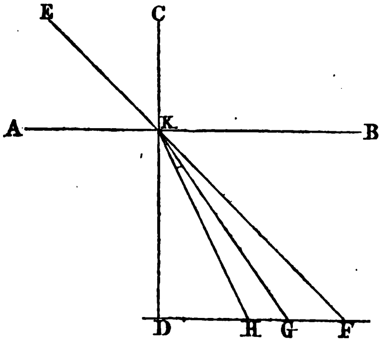


Prop. III. Theorem. When light is refracted towards the perpendicular of the refracting surface, its motion is accelerated; and when it is refracted from the perpendicular its motion is retarded.

This proposition is divided into two cases; first, when light is refracted towards the perpendicular of the refracting surface, and second, when it is refracted from the perpendicular.

First, when light is refracted towards the perpendicular of the refracting surface its motion is accelerated.

Let any particle of light E, move in the direction E G, and be incident on the surface, A B, of the refracting medium A B D F. Now it is evident that (by the hypoth.) the angle D K H is less than D K G; therefore, by the laws of mechanics, the motion of the particle is accelerated. Q. E D.



Secondly, when light is refracted from the perpendicular its motion is retarded. This is quite evident from the last case, for the angle D K F is much larger than D K G, therefore the motion of the particle is retarded. Q. E. D.

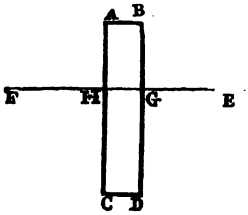
Prop. IV. Theorem. When light passes into any transparent medium, if its velocity does not exceed the attractive power of the medium, it is wholly reflected.

For as the velocity increases when the attractive power diminishes, therefore, when the particle is under the influence of neither of the repulsive forces existing in the medium, it is wholly reflected.

Prop. V. Theorem. The refraction of any particle of light diminishes as its velocity increases.

Since the refraction of any particle of light is caused by the attractive force of any medium and the velocity of that particle compounded, it follows that, whichever of these two forces increases in power, the refraction shall be more or less according to which force it is that increases; if the attracting force of the medium shall increase the refraction of the particle will be greater; if the velocity of the particle become greater, and but the attracting force of the medium remain the same, then it necessarily follows that the refraction shall be less.

Scholium. In a subsequent chapter several experiments will be detailed to support the propositions demonstrated in this.

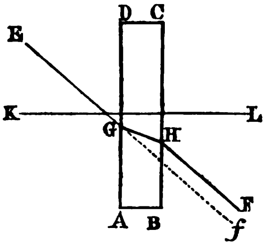


Prop. VI. Theorem. When a ray of light falls perpendicularly upon the surface of a refracting medium whose sides are parallel to each other, it will pass through that medium in the same direction and in the same straight line, and, therefore, does not suffer refraction.

Let E F be the ray incident upon the plane medium A B C D in G, and immergent in H, then will E F be a continued straight line.

For so soon as a particle of the ray has reached the surface G it will pass forward in the same direction as it entered, and as the particles immediately surrounding G are perfectly level with respect to each other, their spheres of attraction must be so likewise; and, consequently, the particle of light being equally attracted every way, is as though it were not attracted at all: when it has come within the attraction of the particles immediately surrounding G, it is violently drawn towards H; the velocity increasing as it moves onward; when it arrives at H the acceleration of its motion is at its height, and so soon as it has passed beyond the medium of H it continues its motion in the same straight line; for at H it is equally attracted on every side, and, therefore, passes forward uninfluenced by the forces exerted by any, moving directly to F. Therefore, when a ray of light falls perpendicularly upon the surface of a refracting medium, Q. E. D.

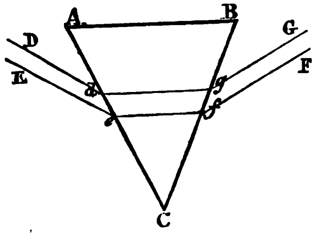
Prop. VII. Theorem. When a ray of light falls obliquely upon the surface of a refracting medium whose sides are parallel to each other, it passes through that medium in the same direction, but not in the same straight line; and therefore it suffers refraction.

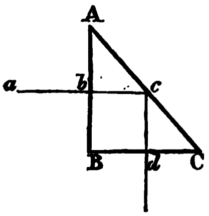


Let E G be any ray of light incident on A B C D in G, it will immerge, after passing that medium, in the same direction H F, but not the same straight line G *f*.

Suppose any particle E of the ray to strike the plane surface in G, when its velocity will be greatly increased by the attraction of all the particles situated between G and *g*, which can act upon it. The impetus of the particle itself would impel it in the direction G *f*, but the force which is supposed to be spread over the surface A D, and to act in the direction K L, necessarily draws it to a greater parallelism with the perpendicular K L, and it therefore moves in some such line as G H; when arrived at H, the force which bent it into that direction ceases, and its own still continuing, it must move in the line H F; as there is no force to counteract that motion; and, therefore, its path H F is parallel to E *f*, or the line which it would have described had no forces operated in its path through the medium. Therefore, when a ray of light falls obliquely, &c. Q. E. D.

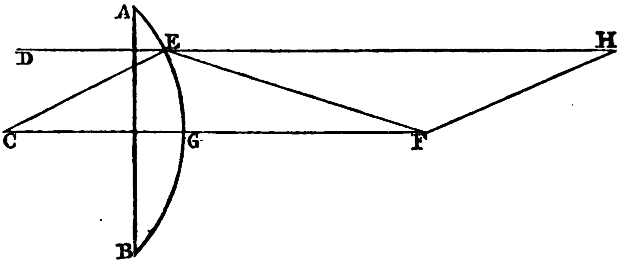
Corol. From these observations it is easy to discover the path of a particle of light when passing through any substance whose surfaces are inclined to each other; as in prisms. Let A B C be any prism, and D *d*, E *e* two rays incident upon it. Let the ray D *d* be refracted in the direction *d g*, then the ray E *e* will be refracted in the direction *e f* parallel to it; for they were supposed parallel before refraction. Again, let the refracted ray *d g* be refracted in the direction *g* G, then will the other ray *e f* be refracted in the direction *f* F, or parallel to *g* G; consequently, if the rays G F be received on white paper, the image at G F will be of the same size and figure which it would be if received on the same paper at D E. This corollary is the very foundation of the explanation of Newton's theory of colours.





Let A B C be any prism, the angle at B being a right angle, and A and C equal to each other: let *a b* be a ray perpendicularly incident upon A B, it therefore passes to *c* without refraction; when it arrives at c it will fall upon A C at an angle of 45 degrees, and, therefore, the conditions answer to those in prop. IV. and it is wholly reflected. This is a fine experiment for illustrating that proposition; for the surface A C reflects the rays as effectually as it would do if foliated.

Prop. VIII. Theorem. When parallel rays fall perpendicularly upon the plane surface of a refracting medium, whose other surface is convex, they are refracted by that medium into a point.



Let C G, D E be parallel rays of light falling upon the plane surface A B of a refracting medium, (perpendicularly,) whose other surface is convex, they will be refracted by that medium into a point F.

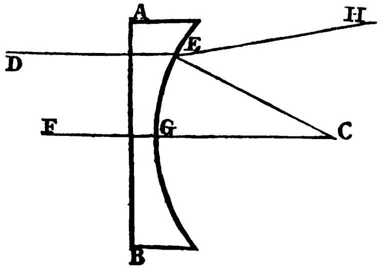
Let C G be a ray falling perpendicularly not only upon the plane surface A B, but also upon the convex surface A G B. Then by Prop. VI. it shall move through the medium without suffering refraction, and pass on in the line C F, the only change made being an increase in its velocity.

Let D E be another ray parallel to the former, falling upon A B perpendicularly, but upon A G B obliquely; it will therefore be refracted as the attractive influence acts perpendicularly, or in the direction of the line C E; supposing C the centre of the convex surface. Let C E represent that attractive force, and let any other line, as E H, which is a continuation of D E, be the force which the particle derives from the velocity of its movement when it has arrived in E: complete the rhomboidal figure C E H F, then by the laws of motion, the particle when arrived in E shall describe the path E F.

The lines D H, C F are parallel, and the line E F makes an angle with the line D H, and, therefore, it makes an angle with the line C F, and if produced, will intersect it. Therefore, when parallel rays of light fall perpendicularly, &c. Q. E. D.

Corol. 1st. If the rays of light had been incident upon the convex surface, it is evident that they would be refracted no more than in this case, for although they undergo refraction at both surfaces, yet their motion is accelerated as much as it is retarded in this case, (Prop. III.) and, therefore, they are refracted equally in both cases. (Prop. V.)

Prop. IX. Theorem. When parallel rays of light fall perpendicularly upon any medium one of whose surfaces is plane and the other concave, they are refracted by that medium diverging.



As in the last Prop. let F G and D E be the incident rays, then F G passes through the medium without refraction. But whereas in the last proposition, the force of attraction C E or C G partly conspired with the direction of the motion of the particles in this it utterly opposes it as much as it is able, and, therefore, F G emerges from the medium with a retarded velocity, and for the same reason, the ray D E after its immersion from E describes the path E H diverging.

Corol. 1st. If the rays fall upon the concave surface, the effect may be deduced from Prop. VIII. Cor. 1. to be the same as in the preceding proposition.

Corol 2nd. If both sides of the medium were equally convex, the effect would be doubled.

CHAPTER III.

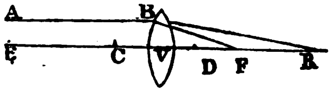
On finding the Foci of Rays refracted by passing out of one medium into another of different density.

From what has been said in the last chapter concerning the passage of rays of light through media bounded by plane and parallel surfaces, the following observations may be deduced.

1. When diverging rays fall upon the surface of a refracting medium they diverge less after refraction than before.

2. When converging rays fall upon the surface of a refracting medium they converge less after refraction than before. This is upon the supposition that the refractive density of the medium upon which the ray is incident is greater than that which surrounds it; if the reverse be the case, or the refractive medium be of less density than that surrounding it, then the rays will diverge or converge more after refraction than before.

To find the focus of parallel rays falling on any refracting medium.



Let v be the lens, having two spherical convex surfaces; let c and D be the centres of those surfaces; let the given ray coincide with the axis of the lens and pass through E V R in a right line; let A B be a ray a little distance from it and parallel to it; the point F, in which such rays would meet, if continued backwards, is sought.

Let R be the point into which these rays come when they penetrate into the glass; that is, R is the imaginary focus of the rays after the first refraction.

Let E be the point to which the rays that proceed from a contrary point would come, if they should penetrate into the glass through the opposite surface, and continue their motion in it; moreover, let the ratio of the sine of incidence in air and sine of refraction in glass be as m and n.

We have EV, EC : : RV, RD : : m : n.
That is EV, RV : : CV, DV
By Comp. & Divis. RE, RV : : DC, DV
By Division CV, EC : : $m-n$: n, that is, $EC = \frac{n \times CV}{m-n}$

The rays which in glass are directed towards R are in air directed towards F in such a manner that RE, RV : : EC, VF : : DC, DV.

If for EC we put $\frac{n \times CV}{m-n}$ the Prop. is changed into this

CD, DV : $\frac{n \times CV}{m-n}$ VF.

Therefore the rectangle of the semi-diameter of the surface is multiplied by the number expressing the sine of refraction in glass, and the product is divided by the difference of the sine in air and glass. The quotient divided by the distance between the centres, that is, by the sum of the semi-diameters; when both surfaces are concave or convex by their difference; when one is concave, and the other convex, there will be given the distance of the point sought from the lens.

Of all transparent solids glass is that which is most frequently employed as a refracting medium; for although its powers are greatly exceeded by some substances, yet the ease with which it is ground and polished is a powerful inducement to use it: there are six shapes into which it is usually cut, and each of these is called a lens.

Fig.

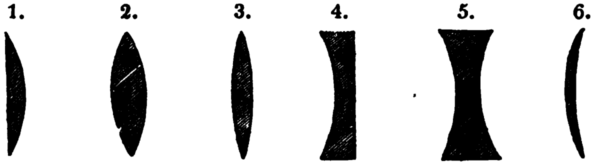
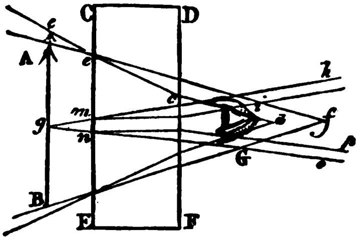


Figure 1 is a plano-convex lens, having one side plane and the other convex; figure 2, a double convex, having both sides equally convex; figure 3 is a crossed lens, and its surfaces are of unequal curvature; figure 4 is a plano-concave lens; figure 5, a double concave, and figure 6 a meniscus. The properties of these lenses may be deduced from the preceding propositions: the focus may be, in all cases, found whatever the refracting power of the medium, by dividing the geometrical focus by $\frac{i-r}{\frac{1}{2}r}$, i being the sine of incidence and r the sine of refraction.

CHAPTER IV.

On the Appearances under which Objects are seen when their images are viewed after Refraction, through Media, whose surfaces are Plane, Convex, Concave, or Cylindrical.

An object which is seen through a medium, which is bounded by surfaces that are parallel and plane, appears larger, brighter, and nearer, than when viewed without subjecting it to the influence of that medium.



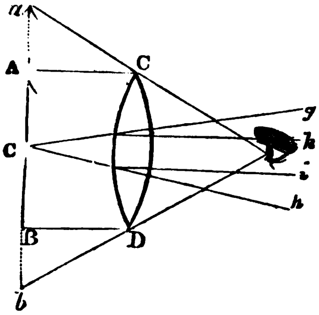
Let A B be any object seen by the eye G through any medium which is bounded by surfaces C E, D F, which are plane and parallel to each other; the object will appear larger, brighter, and nearer, than when viewed without subjecting it to the influence of the medium C D E F.

It appears larger: for let any ray A *b* emanate from *a*, in passing through the medium it is refracted to *c*, and enters the eye in the line *c d*. Therefore the eye refers *c* to *e*, as is shown by the figure, and consequently the object is larger.

It appears brighter: since any ray, as *g h*, which would pass beyond the eye to *h*, is, by passing through the medium so refracted that it pursues the path *g i*, and therefore enters the eye, from which it is evident that the object will appear brighter, as more rays will enter the eye.

It appears nearer: for the rays *i m*, *h m*, intersect each other in *m;* as do the rays on *p n;* and therefore that is the apparent situation of the point *g*. Consequently the object appears nearer; and the effect, both as to magnitude, brightness, and distance, evidently depends on the thickness of the medium.

An object viewed through a convex lens appears larger, brighter, and more distinct than without the intervention of that medium.



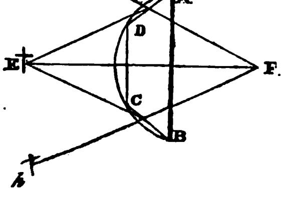
Let A C and B D be two rays which are reflected by the lens to E, where they meet, and are viewed by the eye, their apparent path is referred to *a* and *b*, consequently the object appears magnified in the proportion of *a b* to A B.

The object appears brighter: for let the two rays, F *g*, F *h*, emanate from F. If the lens did not intervene they would move to *g* and *h*, beyond the eye E; but by the intervention of the lens, which renders them less converging, they pursue some path, *k i;* that is, they pass into the eye, consequently the object appears brighter.

As to the distance which the object appears to be from the eye, it varies with the position of the object. If the object is nearer the lens than the natural focus, the rays are so refracted that they diverge less than before, and the object appears where these refracted rays would intersect each other; that is, at a greater distance than the actual situation of the object; but the mind does not conceive the distance to be so great, but imagines the situation of the object to be somewhat between the place where it should appear and where it actually is. This is effected by the concurrent brightness and magnitude of the image. For when the situation of the object is in the natural focus, the mind does not think its distance greater than if it had been viewed by the naked eye, although its distance should appear infinite. If the object be placed beyond its natural focus, the rays which are incident upon the lens, and after refraction, will converge, intersect each other, and diverge. If the eye be placed in such a position, that the rays proceeding from the extremities would make no greater angle than they would do if the lens were not interposed, the object would appear much the same size and brightness as without the lens, and in the same position. But if the eye be situated further off, the object becomes magnified, and brighter, and therefore approaches the lens.

An object viewed through a concave lens appears nearer, smaller, and not so bright as when the lens is not interposed. The objects appear in this manner on account of the diverging produced by the lens, as is evident from what was said concerning convex mirrors.

When the object is situated beyond the focus of parallel rays, and the eye at the same distance on the other side, a pendulous object may be seen in the focus; the remarks made on the pendulous images in concave mirrors are equally applicable to these.



Objects are multiplied when viewed through a medium which has several surfaces: if a lens, A D B, be ground on its convex side into several plane surfaces, an object appears multiplied according to the number of those surfaces. Let the lens be ground into three faces, A D, D C, C D, an image of the object E will appear; (*g* and *h*;) for the rays incident on those surfaces are refracted to F, where they may be viewed by the eye, and being referred by it to *g* and *h*, an object will appear in each of these surfaces.

When the surfaces of media are convex and cylindrical, they collect incident rays into a bright line, instead of a spot, and therefore magnify objects in breadth, whilst the length remains the same; and the laws which belong to convex lenses are equally applicable to these.

CHAPTER V.

History of several discoveries relating to the Refraction of Light.

It does not appear that the ancients were acquainted with the real cause of refraction, although they might have observed some of the more prominent phenomena. The first rational explanation to be met with on the subject is said to be in the Treatise on Optics, by Claudius Ptolemy, who assigns the changes made on incident rays to the attractive power of the medium through which they pass.

Archimedes, who lived 1350 years before Ptolemy, wrote a treatise on the appearance of a ring, when under water; which is a phenomena entirely owing to refraction. In the Life of Pythagoras, written under the name of Jamblicus, (although it is not decided whether it is the Syrian or he that was born at Colcher, for they were contemporary,) accidental mention is made of optical instruments which magnified objects, and must have been convex lenses. Pliny observes, that Nero made use of emeralds, whose surfaces were convex, to assist him in viewing shows. Seneca knew that when the sun's light falls upon a triangular prism it is reflected, and produces colours; and he says, that "Letters though minute and obscure, appear larger and more distinct when viewed through a glass bubble filled with water." But these bubbles were known long before the time of Seneca; for not unfrequently they are found in places where Druidical remains are discovered, as well as lenses made of rock crystal of a regular form and polished, of various sizes, some of them globular, and others lenticular. One of these, which was given by Dr. Woodward to the University of Cambridge, is an inch and a half in diameter. It is more than probable that these lenses were used for the purpose of ignition; but whoever had occasion to handle or use them, could not but have observed their magnifying power. There are several other passages which appear to relate to this subject, in antient authors. Aristophanes, in his comedy of "The Clouds," which was written to ridicule Socrates, introduces that great man as examining Stripsiades on the method which he discovered to get rid of his debts. "I'll use my glass that I light my fire with, and if they bring a writ for me I'll place my glass in the sun, at a short distance from it, and set it on fire." Pliny says, that globes of glass, if exposed to the sun, will fire cloth and may be used inetead of caustics. Plautus also mentions burning glasses.

Alhazen, who wrote on many optical phenomena, treated on refraction, in the explanation of which he followed the opinion of Ptolemy. He knew the effect of the atmospherical refraction, in elevating the heavenly bodies higher than their true altitudes; showed that it contracts the vertical diameters of the sun and moon, and believed it to be the cause of the twinkling of the stars. This reflection he supposed to be occasioned by the different density of the air, at different distances from the earth.

Vitellio, who wrote a Treatise on Optics, showed that when light passes through any medium, a considerable portion of it becomes extinct. He formed a table of the different refractive power of air water, and glass, and showed that refraction was necessary to form a rainbow.

Roger Bacon accounts for the superior magnitude of the stars when seen in the horizon, than when seen in the zenith, in the following manner. "The rays of light coming from the stars are made to diverge from one another, not only by passing from the rare medium of ether into the denser one of our surrounding air, but also by the interposition of clouds and vapours, arising out of the earth, which repeat the refraction and augment the dispersion of the rays, whereby the object must needs appear magnified to our eye."

John B. Porta, whose name has been before mentioned, was the inventor of the camera obscura, (darkened chamber.) He formed an association called "An Academy of Secrets," and before he was fifteen years old published his "Magia Naturalis," in which he describes the camera obscura and magic lanthorn.

Shortly after this time Snellius discovered the method of measuring refraction by means of the sines. Many have believed that Des Cartes was the first inventor, as it appears in his works, but Huygens declares, on his own knowledge, that Des Cartes had transcribed it from the papers of Snellius.

Des Cartes explained optical refraction on the principle of the mechanical resolution of forces. Dr. Halley particularly honours this great man when he says, that, "although some of the ancients mention refraction as the effect of a transparent medium, yet Des Cartes was the first who discovered the laws of refraction, and reduced Dioptrics to a science.

To determine the value of the refraction of water the Royal Society, in 1664, made an experiment, the result of which was, that if the angle of incidence was 40°, the angle of refraction was about 30°; that the refraction of salt water was greater than that of fresh; and that a solution of salt petre was a little more, and a solution of alum a little less refractive than common water. From these and other experiments, they discovered that the refraction of any medium is not in proportion to their density.

In 1708 the Royal Society made experiments to determine the refractive power of atmospheric air. When the barometer was at 29°,7½, and thermometer 60°, they found the sine of incidence in vacuo, to the sine of refraction in common air as 1.000.000 to 999.736, which was afterwards confirmed by the Academicians of Paris.

A short time before this, Newton had made his great discovery concerning the different refrangibility of the rays of light, and Bartolinus concerning double refraction. But as these subjects form a distinct part of optics, their history is deferred.

PART THE FOURTH.

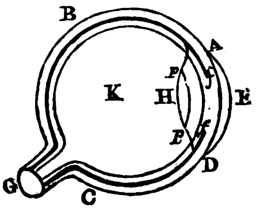
THE THEORY OF VISION.

CHAPTER I.

On the Anatomy of the Eye.

The eye is the chief of all optical instruments, being the organ by which we see objects, and through whose medium they are perceived. Of all parts of the human body, the eye appears the most refined in its operations, and delicate in its construction. The different parts of the eye may be classed under two heads,—the eye itself; and its appurtenances or apparatus.

The most striking and prominent of the appurtenances of the eye is the palpebræ or eye-lids. The palpebræ are lined with a soft substance, which, extending from them, covers a part of the eye, and passes under the name of tunica conjunctiva, or white of the eye. Its uses are to prevent the friction between the eye and the palpebræ, to defend the eye from dust, &c.



The borders of the eye-lids are ornamented with a row of stiff hairs called cilia, or the eye-lashes, which are for defence as well as beauty.

The external appearance of the eye itself is a lenticular section, the two extremities, or corners of which, are called canthi; the corner nearest the nose being the canthus major, and the other the canthus minor.

Towards the upper part of the eye is the lachrymal gland, which furnishes a fluid called tears, and is spread equally over the eyes by means of the palpebræ, and to favour the escape of this fluid there is a small hole, in each eye-lid, called punctum lachrymale, near which is a little fleshy substance called caruncula lachrymalis, which, by preventing the eye-lids towards the canthus major from closing completely, partly answers the end of the puncta lachrymalia. These are the appurtenances of the eye, and may be said to have no effect whatever on vision.

The figure of the eye as seen above, appears nearly spherical. Its parts are, A B C D, an outward coat of a white and opaque substance resembling white enamel; it is called tunica sclerotica. The part A E D of the tunica sclerotica is called the cornea, which is very transparent.

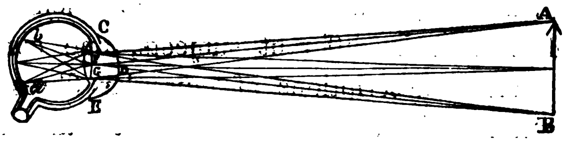
The next, or middle coat, is called the choroides, or uvea. This coat is very tender and full of vessels; it joins the iris, *f f*, which is an opaque membrane of different colours in different subjects, and composed of two distinct descriptions of muscular fibres. The iris is perforated in the centre. When the light is oppressive to the eye, the muscular fibres which are of a circular form, contract the diameter of the pupil, or perforation: in the opposite case, the radial set of fibres dilate the pupil.

The third and last coat is an expansion of the optic nerve G: this is called the retina. The junction of the optic nerve and retina is not in the middle of the retina, but more towards the canthus major and the nose. Between the tunica choroides and retina there is interspersed a black powder, called pigmentum nigrum.

The aqueous humour is a fluid substance lying beneath the cornea, and, filling up all the cavity about *ff*, gives a spherical appearance to that part of the eye.

The crystalline humour, H, is enclosed in a very transparent membrane, called aranea: from the aranea proceed the radial fibres, *pp*, which join it to the iris. These fibres, by dilating or contracting after the convexity of the crystalline humour, move it forwards or backwards, so as to adapt its focal distance to the distances of different objects. The crystalline humour is a kind of jelly, perfectly transparent, which answers the purpose of the lens.

The vitreous humour, K, fills up the remainder of the eye, and is therefore in greater quantity than either of the others; it is of a gelatinous substance, serving to keep the crystalline humour and the retina at a due distance from each other.



The manner of the action of the eye upon the visual rays is thus explained; Let A B be an object, and let the pencil of light, A F, enter the eye; now since the cornea is a meniscus, with a convexity prevalent, the pencils emanating from *a*, by passing through, are rendered more convergent. They all now pass through the crystalline humour, and by its centicular form are refracted to *a*. In like manner, the rays emigrating from B are refracted to *b*, and therefore an inverted picture is formed on the retina of the object A B.

Since the image formed in the eye is inverted, many have been surprised that objects should be seen in an erect posture. The question certainly does not belong to optics, since this science considers only the seeing of objects, and not the perception of them. But as most authors have treated on this subject in their works on optics, it is, perhaps, necessary to elucidate it here. By some it is positively asserted, that objects are seen inverted, and that it is the sense of feeling that corrects this. In support of this they state, that if as soon as children begin to take notice of things, a stick gilded at oneend be presented to them, they snatch at the other. But this is not always the case; and in adults who have been born blind, but who have the power of expressing all that occurs to them, and who have received sight, the case never occurred, for they all see objects in an erect posture. This was the effect in the famous case of Cheselden's patient, for he never saw objects inverted, and yet he was of sufficient age to judge for himself. It is impossible that the sense of feeling should correct that of sight. As a simple illustration, suppose an adult hitherto blind to receive his sight, and to be presented with a stick one end of which is knobbed. Suppose the stick to be held in such a manner that the knobbed extremity is uppermost. The patient perceives as though the other extremity was the highest. He puts out his hand to touch the knob, his eye now represents his hand in moving downwards, whilst he is conscious it moves in an opposite direction. This method of solving the difficulty involves another far more objectionable and inexplicable, for there would be a confusion of the senses.

After all that has been said, the truth of the matter seems to be, that those who consider this as a difficulty, have not examined the cause in its utmost extent. An illustration may perhaps exhibit the subject in a clearer light. For in the Newtonian telescope, after reflection from the plane mirror, the image of the object is inverted, and there the reflection ends; but by means of refraction through three eye glasses, the image is made to appear erect. Just so with the eye, after the image is formed upon the retina in an inverted position, the sense of seeing ends, and that of perception begins. Although ignorant of what occurs between the retina and the sensorium, (if we may be allowed the use of term,) after the formation of the image upon the retina, yet we are conscious that we see this in a proper position, and it is as certain that there are means of erecting the object from its position on the retina. For in whatever position the eye may be placed, with regard to the object, we see it as though the eye were not moved at all. So if any object, as an upright stick, be observed, it appears in its proper position, yet if the head be turned a semicircle, although the picture on the retina be inverted, with respect to the position it was in before, yet still the object is seen in its proper position. Therefore it is necessary to perceive objects in there proper positions, that they shall form an inverted image of themselves upon the retina, which the mind perceives erect by means of some unknown event or events occurring between the retina and the sensorium, which is perhaps the only unexceptionable explanation that can be given.

As we have two eyes, and an image is formed on the retina of each, why do we not suppose two images or two objects where there is but one, or in other words, why do we not see double ? Sir Isaac Newton thought that because the optic nerves join before they reach the brain, that the difficulty of the question was removed, but cases have occurred in which there has been no union of these nerves before there arrival at the brain, and yet the subject saw singly. Others have supposed that the syncronous vibration of the nerves easily accounts for the difficulty, but Dr. Wells has shown that none of these hypotheses will account for it with any degree of probability, and he therefore proposed another, which certainly in appearance surpasses them all. When an object is placed in that situation, in which it may be most distinctly seen, it is in what is denominated the Optic axis of the eye. When both eyes are directed to any object, whose distance is not very great, the Optic axes form two sides of a triangle, of which the interval between the point where the axes enter the eyes is the base, and may be denominated the visual base ; a line which is drawn perpendicularly to it and passing through the point of intersection of the optic axis, is the common axis. Now the object which is situated in the optic axis, is referred by the mind to the common axis, and therefore appears in that line. Objects whose situation is in the common axis, do not appear in that line, but in the axis of the eye by which they are not seen: and objects whose situation is in any line drawn through the mutual intersection of the optic axes to the visual base, do not appear in that line, but in another, drawn through the same intersection to a point in the visual base, whose distance is half this base from the similar extremity of the former line toward the left, if the objects are seen by the right eye; but toward the right, if seen by the left. When the question is concerning an object situated at the concourse of the two optic axes, it is seen single on account of the similar appearances in size, shape, and colour which are seen by both eyes in the same direction; or, if you will, in two directions which coincide with each other throughout their whole extent. It therefore is of no consequence whether the distance be smaller or greater; whether it touches our eyes, or is at an infinite distance: and this is the reason why objects appeared single to the young gentleman couched by Cheselden, who saw single before he had learned to judge of distance by sight. When two similar objects are placed in the optic axes, one in each, at equal distances from the eyes, they appear in the same place, and therefore as if there was but one; for the same reason that a single object appears single, when placed at the intersection of the optic axis. It seems only necessary to determine, whether the dependance of the visible directions upon the actions of the muscles of the eyes be established by nature, or by custom. But facts are here wanting. As far as they go, however, they serve to prove that it arises from the original principle of our constitution. For Mr. Cheselden's patient saw objects singly, and consequently in the same direction with both eyes, immediately after he received his sight; and persons affected with squinting, from their earliest infancy, see objects in the same direction with the eye they have not been accustomed to employ, as they do with the other which they have constantly used.

There are three suppositions concerning the situation of the seat of vision. I. That it is in the retina; II. in the choroides; and III. that the retina and choroides are both necessary to vision. It had always been supposed that the retina was the seat of vision, till Mr. Marriotte made an experiment which seemed to render it doubtful. Having placed three pieces of paper on the side of the room, two feet from each other, he kept one eye shut, and the other turned obliquely to that paper opposite the eye which was shut; and gradually retiring from a position close to them, he found that there is a situation in which the middle mark will disappear, while the other two, are very plainly distinguishable. This led Mr. Marriotte to suspect that the retina is not the proper seat of vision, since it is not opaque.

On the other hand, it is argued that the transparency of the retina is partial; and that the opacity of the choroides, upon which Mr. Marriotte laid much stress, is not constant, being different colours in different animals.

De la Hire supposes both the retina and choroides necessary to vision; but after a great discussion, public opinion has declared in favour of the retina; for the choroides, in many instances, is impenetrable to the rays of light, whereas the retina is nothing else than a nerve.

The place in which the mind judges any object to be situated after refraction, is in that line produced, in which the axis of any particle of rays, emanating from it, proceeds after refraction through that medium. The magnitude of any object is measured by the angle under which that object appears; and vision must be brighter, in proportion to the greater number of rays which enter the eye; and in most cases distance is judged of by magnitude, brightness, and distinctness, for all this is evident from what was demonstrated in the last chapter.

The nearer any object is to the eye, the larger it will appear, (and this is one of the fundamental propositions in perspective,) for the angle which it makes decreases, and the distance increases; and the reverse.

The least angle under which any object may be seen varies with the circumstances of situation &c.; in some cases an object, though it subtend an angle of one minute, while in other cases objects may be seen when they subtend an angle of only one second. If a black spot be made on white paper, and its diameter be less than one minute it is invisible; but a spider's web may be seen when its diameter is only one second, or even less than that. But a line of any description, makes a much greater impression on the retina, than a spot can possibly do; and perhaps it may be owing to this, that the line though of less diameter than the spot, shall be clearly visible. But this must vary again with the quantity of light incident upon it,

To the indefatiguable research of the celebrated Dr. Young, to whom science is so much indebted, we are principally obliged for the following dimensions of the eye.

	Inches
Length of the optical axes.	0. 91
Vertical chord of the cornea.	0. 45
Horizontal chord of the cornea.	0. 47
Opening of the pupil seen through the cornea.	0. 27 to 0. 13
Radius of the interior surface of the crystalline lens.	0. 30
Radius of the posterior surface.	0. 22
Principal focal distance of the lens.	1. 73
Distance of the iris from the cornea.	0. 10
Distance of the iris from the anterior surface of the crystalline.	0. 02
Range of the eye, or diameter of the field of vision.	0. 110°

CHAPTER II

History of several Discoveries relating to Vision.

Empedocles and Plato supposed vision to consist of particles which emanate from the eye, meeting others which proceed from objects without. It is said that Metrodorus, who lived about 453 B. C. was of this opinion, but his works are lost: he was master of Hypocrates, the physician. Others, of whom Pythagoras was chief, supposed it to arise from the rays received into the eye; and others, from rays or particles emitted by the eye, of which opinion was Heliodorus Larisseus, who has thus explained it in his works on Optics, οτι μεν ουν τιροβολας τινας, &c. For that we emit from ourselves certain particles against the objects which we see, the very form of the eye declares; for it is not concave, and therefore is not fitted by nature for the reception of anything, as the other members are, but it is globular. And that it is light which is emitted, the shining splendour of the eye and some who can see by night, without the assistance of foreign light, testify. This is the case with certain animals who seek their prey by night, and the Roman Emperor Tiberius was celebrated for the same circumstance.

An examination of the first and last of these opinions would be unnecessary, as it is evident that things would then be seen in the dark as well as in the light; or in other words there could be no such a thing as darkness. The hypothesis of Pythogoras, who was generally correct in his suppositions, is considered as accurate to the present day. The light of the sun falls upon objects, and is reflected by them into the eye, where striking upon the retina, they are perceived by the mind. Roger Bacon, however, supposed the opinion of Heliodorus to be true.

Francis Maurolycus, a Sicilian Abbot, in 1572, published a Treatise on Optics, under the title "De Lumine et Umbra," in which he showed the action of the crystalline humor in converging the rays of light, and discovered the theory of spectacles, that those who were myopes, or short-sighted, required concave lenses to cause the rays to diverge before their entrance into the eye; and that those who were presbytæ, or long sighted, required convex lenses to make the rays converge.

John B. Porta, while yet a youth, made great advances in this science, discovered the resemblance of the camera obscura to the eye; and Kepler shortly after discovered that the image formed upon the retina is inverted by the mind, which he never attempted to account for, eluding it by saying it did not belong to Optics.

Scheiner, who has rendered his name famous by his discovery of the spots on the sun, demonstrated that it is the retina which is the proper seat of vision by placing objects before the retina of various eyes which he had prepared. Des Cartes showed how the mind judges of magnitudes, situations, distances, &c. by the inclination of the optic axis, and advances further than any of his predecessors.

In 1709 Dr. Berkeley published a singular and in some respects a useful work, which he called "An

Essay towards a new Theory of Vision." He will not, however, admit that it is by certain lines and angles, that the various notions of distance are introduced to the mind. "I appeal," says Berkeley, "to experience whether any one computes distance by the bigness of the angle, made by the meeting of the two optic axes; or whether he ever thinks of the greater or less divergency of the rays which arrive from any point to his pupil; nay whether it be not perfectly impossible for him to perceive, by sense, the various angles wherewith the rays, according to their greater or lesser divergency, fall upon his eye." Whether the Doctor reasons upon fair premises or not I leave my readers to determine, but I shall not be deceived if they are little inclined to receive them.

It is not fit that the theories of perception should be noticed in this place, for it would lead us, it is feared, into a train of thought little compatable with the spirit of investigation. The endless disputes of the metaphysicians on this subject are well known, and it will be easy to refer to the first chapter of Stewart's Elements of Mental Philosophy, and the fourth, fifth, and sixth chapters of Dr. Reid's Inquiry, where the subject is fully discussed.

PART THE FIFTH.

ON CHROMATICS,

OR

THE THEORY OF COLOUR.

In the corollary of Prop. VII. Chap 2, on the Laws of Refraction, it was demonstrated, that if a ray of light fall upon a medium whose surfaces are inclined to each other, it will be refracted, so that if the rays, after their passage, be received upon a paper, the image will be of the same size and figure as if it had been received on paper before its passage. But upon putting this to the test of experiment, we find that it does not hold good; for instead of there being a plane white spot, as it would appear there ought to be, the light assumes seven beautiful hues, exactly such as those of a rainbow.

Let a ray of light enter through a partition by a hole, and let it be received on a glass prism, now, according to the corollary it should form, on any dense body against which it strikes, a round spot: but it is found to exhibit a long, rectangular figure, bounded by semicircular ends. The colours are arranged in this order:

violet, indigo, blue, green, yellow, orange, and red; the red being the least refracted, and the violet the most: which arises from the nature of the light itself some particles of which are more refrangible than others. For if this spectrum, as the refracted figure is called, be received on a board that is perforated so as to allow one ray of light, or in other words, one colour, to pass; that ray will not be changed by any refraction it may afterwards suffer; but continues the same, both as to colour and refrangibility. And if all the colours be united again, by means of a lense, they will form one colour when compounded, and that colour is the original white.

Different substances disperse the light differently: glass which contains a large quantity of lead, disperses the light much more than glass composed of alkaline salts.

The following abridged Table of Dispersive Powers, it may not perhaps be improper to insert.

	Dispersive Power	Index of Diff. Refrac. for Red and Violet Ray.
Chromate of Lead	0. 400	0. 770
Oil of Cassia	0. 139	0. 089
Phosphorus	0. 128	0. 156
Oil of Bitter Almonds	0. 079	0. 048
Oil of Cummin	0. 065	0. 033
Sulphate of Lead	0. 060	0. 056
Resin	0. 057	0. 032
Flint Glass	0. 052	0. 026
Nitric Acid	0. 045	0. 021
Muriatic Acid	0. 043	0. 016
Sulphate of Iron	0. 039	0. 019
Diamond	0. 038	0. 056

	Dispersive Power.	Index of Diff. Refrac. for Red and Violet Ray.
Castor Oil	0. 036	0. 018
Water	0. 035	0. 012
Sulphuric Acid	0. 031	0. 014
Rock Chrystal	0. 026	0. 014
Sulphate of Strontites	0. 024	0. 015
Cryolite	0. 022	0. 007

From what has been said, it will be understood that different substances have different dispersive powers, that is, powers of seperating the coloured rays of light; and it may also be proved that those seperated rays of light have different refractive powers: the red being the least, and the violet the greatest.

The first proposition Sir Isaac Newton gives, in his Treatise on Optics, is, "Lights which differ in colour, differ also in degrees of refrangibility." This he proved by some interesting experiments. In his first experiment he took a piece of oblong paper, which he cut so that the sides were parallel; he then drew a perpendicular right line from one side to the other, so as to divide it into two equal parts. One of these parts he painted red, the other blue. This paper he viewed through a glass prism "whose two sides through which the light passed to the eye," says the immortal philosopher, "were plane and well polished, and containing an angle of about 60°: which angle I call the refracting angle of the prisms. And whilst I viewed it, I held it before a window in such a manner that the sides of the paper were parallel to the prism, and both those sides and the prism parallel to the horizon, and the cross line perpendicular to it; and that the light which fell from the window upon the paper, made an angle with the paper equal to that angle which was made with the same paper by the light reflected from the eye." Now, he observed that, when the refracting angle of the prism was turned upwards, the blue half was raised by refraction higher than the red, and when the refracting angle of the prism was turned downwards, the blue half was depressed lower than the red. From this it was proved that blue colour suffers a greater degree of refraction than red.

This experiment he followed by another, which served to convince him of the fact already discovered. Around the paper which he used in the foregoing experiment, he twisted black silk in such a manner that it might appear as if black lines were drawn across it. This paper he fixed in an upright position, and placed a candle below in that situation which illuminated it strongly. At a distance of six feet and one or two inches, he placed a glass lens to collect the rays which proceeded from the paper, and made them converge at the same distance on the other side of the lens, so as to form the image of the coloured paper upon a white paper placed there. Now, this white paper he moved nearer to, or farther from the lens to find that point where the image of the parts was most distinct. But he discovered, by noting the point where the image of the silk was most distinct, that, when the black marks of the blue were distinct, the marks on the red were confused, and the contrary. By a closer examination he found that the white paper was nearer by an inch and a half to the lens, when the image of the blue colour appeared most distinct than when the image of the red was most distinct. The blue therefore was refracted more than the red, and converged sooner by an inch and a half, and therefore must be more refrangible.

These experiments were sufficient to convince Sir Isaac that lights which differ in colour differ also in degrees of refrangibility. He then proceeded to prove in a variety of propositions that "the sun's direct light," we use the words of Mac Laurin his great commentator, "is not uniform in respect of colour; not being disposed in every part of it to excite the idea of whiteness which the whole raises; but, on the contrary, is a composition of different kinds of rays, one sort of which, if alone, would give the sense of red, another of orange, a third of yellow, a fourth of green, a fifth of light blue, a sixth of indigo, and a seventh of violet; that all these rays together, by the mixture of their sensations, impress upon the organ of sight the sense of whiteness, though each ray always imprints there its own colour; and all the difference between the colours of bodies when viewed in open day light arises from this, that coloured bodies do not reflect all sorts of rays falling upon them in equal plenty; the body appearing of that colour of which the light coming from it is most composed."*

These propositions seem to comprehend all that can be said on the subject of Chromatics, and may easily be illustrated.

That the light of the sun is composed of rays differently refrangible, is proved by the following experiments. Place a lens in the shutter of a window, and let the room with which it is connected be darkened, and the prism be so fixed that the sun's rays may be refracted towards the opposite wall. Let the axis of the prism be perpendicular to the incident rays, and a sheet of white paper be placed at a distance to receive the image. Now beams of light passing through the prism are parted into rays which exhibit all the colours before mentioned, the violet ray being most refracted, the red least refracted. It is here evident, that the white light of the sun is actually divided into seven different colours. The question which Sir Isaac now asked was, whence does this inequality of refraction arise; is it that some incident rays are constantly refracted more, and others less; or does it arise from the disturbing and shattering of one and the same ray. This question may be satisfactorily answered by a consideration of the following experiment.

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* See Mac Laurin's Philosophy of Newton, 4to. edit. book iii. p. 318.

Tie two prisms so together that they may form a parallelopiped, and place them in a beam transmitted through a small hole in the window-shutter. Beyond the prisms place a third to refract the emergent light, and cast that light on a piece of white paper as in the former experiment. Turn the parallelopiped upon its axis, and it will be observed that, when the contiguous sides of the prisms are so oblique to the incident rays as to cause them to be reflected, those rays which in the third prism had suffered the greatest refraction, and painted the paper with violet and blue, are by a total reflection taken out of the transmitted light, the rest remaining. But by turning the prisms the other rays also vanish, in an order according to the degrees of their refrangibility. From this Newton deduces, by a beautiful reasoning, that the light which emerged from the prisms must be compounded of rays differently refrangible, because the more refrangible rays may be taken, while the less refrangible remain. Moreover the light refracted from the two prisms must have been restored to its pristine condition, for what change it suffered by the refraction of one superficies was altered by the contrary refraction, and thus "became of the same nature and condition as before its incidence on those prisms;" and was therefore composed of rays differently refrangible before its incidence.

Other observations have determined the different refrangibilities of coloured rays. The following will be the result with water,

Violet	1. 3442
Indigo	1. 3413
Blue	1. 3378
Green	1. 3358
Yellow	1. 3336
Orange	1. 3317
Red	1. 3310

Dr. Wollaston, by observations on a narrow line of light, has determined that there are four primary colours, red, green, blue, and violet, which respecttively occupy 16, 23, 36, and 25 parts in length of the spectrum.

It is necessary here to remark, that a beam of light once broken down by a prism, cannot undergo farther decomposition by causing any portion of coloured light to pass through a second prism; therefore rays of any one colour are said to be homogeneous, but those not alike refrangible are called heterogeneous.

But although a coloured ray cannot be again affected by any refraction, yet if a convex glass be held between the paper and the prism, used in a former experiment, so as to collect all the rays which proceed from the prism, a white light will be produced. This proves that the coloured rays together, by the mixture of their sensations, impress upon the organs of sight the sense of whiteness, though each ray, divided from the other rays, imprints its own colour.

The colours of all objects are easily explained upon the principles above mentioned; for a body which is yellow has the property of reflecting yellow rays much more powerfully than any others; a body which is white reflects all the incident light, and one appearing black absorbs it all.

Sir Isaac Newton having placed a glass lens of a long focus upon a plane glass, by pressing it, colours very soon emerged, and distinctly appeared. There was a pellucid central spot, and round it rings of blue, white, yellow, and red; the blue was very little in quantity, nor could he discern any violet in it; but the yellow and red, were very abundant, extending as far as the white, and four or five times as far as the blue. The circuit immediately succeeding these, consisted of violet, blue, green, yellow, and red; all these were copious, and very vivid, except the green, which seemed very faint when compared with the others. Of the other four, the violet was least in extent, and the blue less than the yellow and red. The third circle of colours was purple, blue, green, yellow, and red. The fourth circle consisted of green and red; and of these the green was most copious and lively; but there was neither violet, blue, nor yellow; and the red was very imperfect and dirty. All the succeeding colours were less distinct, and after three or four revolutions ended in a perfect whiteness.

As these colours varied as the distance of the glasses from each other, Sir Isaac thought, that they proceeded from the different thickness of the plate of air intercepted between the glasses; this plate of air being disposed according to its thickness to transmit, or reflect, this or that colour. By measurement it appears that any particular colour is disposed to be reflected, when the thicknesses of the plates of air are as the numbers 1, 3, 5, 7, 9, &c., and that the same rays are disposed to be transmitted at the intermediate thicknesses 0, 2, 4, 6, 8, &c. The thickness required to reflect the colours of any series, is different in different obliquities; for if the light fall obliquely, the rings immediately dilute and enlarge themselves. The following is the law by which you may discover the thickness any thin plate, of any substance, must have at the place where any given colour, in any series, is produced.

As the sine of the angle of incidence at the common surface, is to the sine of the angle of refraction out of the given medium into air; so is the thickness of a plate of air which exhibits the given colour, to the thickness of the given plate.

PART THE SIXTH.

ON INFLECTION.

If any thin objects as hairs, &c., be placed in a beam of light which enters through a small aperture into a dark room, the shadow of them will be increased. It will also be observed, that these shadows are all bordered with three parallel fringes of coloured light; which decrease in distinctness, as they are more distant from the shadow. The colours of the fringes are as follows.

First Fringe—Violet, indigo, pale blue, green, yellow, red.

Second Fringe—Blue, yellow, red.

Third Fringe—Pale blue, yellow, and red.

When the shadow, itself is examined, we find that it is also divided by parallel fringes which, to distinguish them from the external of which we have spoken, are called internal. This was first observed by Maraldi.

This property of light, called inflection because the phenomena it exhibits are supposed to arise from diffraction of light, was discovered about the middle ot the 17th century, by Father Grimaldi. Dr. Hooke, however, preferred a claim to the discovery; but it is only necessary to say that Grimaldi published an account of it in his "De Lumine, Coloribus, et Iride" in 1666, Dr. Hooke in 1672.

Grimaldi, having introduced a ray of light into a darkened room through a very small aperture, observed the beam to diffuse itself it the form of a cone, When he placed an opaque body in the light, and received its shadow on a piece of white paper, he was surprised to find it broader than the rays, passing in a right line by the extremities of the object, should have been. He was not however less struck with the appearance of streaks of coloured light along the lucid part of the base. Each of these being bound on the side next the shadow, by blue; and on the other, by red. But these streaks were not all of the same breadth, but grew narrower as they receded from the shadow.

He farther observed, that the shadow itself did sometimes show coloured streaks, not very unlike the lucid border which surrounded the shadow. These were more distinct when a thin narrow plate was used, than when he made a hair or a needle the object; and the number of streaks increased with the breadth of the plate. But with the same plate, Grimaldi could at pleasure increase or decrease the number of streaks, by changing the distance at which the shadow was received; and by various observations he discovered that their breadth increased, as their number decreased; and the reverse.

It is unnecessary to record the experiments of Dr.

Hooke, for they tend to the same purport as those of Grimaldi; and, indeed, chiefly differ from his in the manner of conducting them.

If a large beam of light be let into a room, and be divided by the edge of sharp knife, whose plane is at right angles to the direction of the beam, which is received on a white screen, the light appears to project two luminous streams, which have been compared to the tails of comets. If two knives, whose edges are perfectly straight, be set parallel to each other, and one of them be so arranged, that by means of a screw, its distance from the other may be varied and measured, a beam of light being suffered to pass between them, it will be observed, that as soon as the two knives are brought within a short distance of each other, coloured fringes appear on each shadow, and become larger and and more distinct, as they approach each other. When within about the 400th part of an inch, they entirely disappear; the light passing between them enlarges, a shadow appears and divides the light into two equal parts. As the knives approach, the shadow grows broader, and the light decreases, until upon their contact it vanishes.

To account for these appearances, Sir Isaac Newton supposed, that all bodies act upon the particles of light, ATTRACTING THEM WHEN AT A CERTAIN DISTANCE, AND AT GREATER DISTANCES REPELLING THEM; that these actions are stronger on those rays which pass nearer body, than on those at a greater distance; therefore such rays as are parallel before their arrival in the vicinity of the body, being variously deflected, must, after passing, diverge from each other; and at the limit where attraction ceases, repulsion begins; and that this limit may differ in different coloured rays, and cause the fringes.

M. Fresnel has made several discoveries on the inflexion of light, which are considered very confirmatory of the Huygenian theory of light. In these he was much assisted by discovering that fringes, and other appearances, might be viewed by an eye-glass without first being received on a screen, so that by adapting a micrometer to the eye glass, he was enabled to determine the breadth of the shadows and colours to the two hundredth of a millimeter.

In the course of his observations he found that the distance of the radiating luminous point had very great influence on the results, for the rays suffer less inflection, in proportion to the distance from which they diverge. When he measured the inflection of the same fringe from different distances behind the inflecting body, the distance of the radiant point being the same, he found it to differ at different distances; therefore the successive positions of the same fringe are not in a straight line, but in the form of a curve, whose concavity is towards the inflecting body. The lines joining the different positions of the fringe are hyperbolas, having for their common foci the radiating point and the edge of the inflecting body.

Dr. Brewster made several successive experiments on thin leaves of substances, and masses of the same. He examined the effects on platinum, and the inflecting powers of a glass cylinder immersed in fluids of the same refracting powers as itself; and concluded from the results, that light was not inflected by any force inherent in the reflecting bodies, but in the light itself, and considers it as a property which always shows itself, when light is stopped in its progress.

The cause of those fringes of colour which are observed in the interior of the shadow was first explained by Dr. Young. This great philosopher has shown that they are formed by the interference of two portions of light, from the opposite side of the inflecting body. Now when light is admitted through two small holes, situated very near each other, into a dark room, a series of fringes is produced, which may be effected by two small mirrors, situated in the same plane.

We have already mentioned the name of Maraldi, but the experiments which he made deserve to be more particularly noticed. This philosopher was perhaps the first after Newton who made any valuable discoveries on the inflection of light, and the partial illumination of their shadows.

He prepared a cylinder of wood three feet long, which he exposed to the light of the sun. When the shadow was thrown beyond a certain distance it appeared to be of two densities, "for its two extremities, in the direction of the length of the cylinder, were terminated by two dark strokes, a little more than a line in breadth. Within these dark lines there was a faint light equally dispersed through the shadow, which formed an uniform penumbra, much lighter than the dark strokes at the extremity, or than the shadows received near the cylinder."

In proportion as the cylinder is removed to a greater distance from the paper, the penumbra grew lighter, and diminished in breadth, but the black lines remained unaltered in breadth, though as the penumbra decreased the lines approached until the penumbra vanished.

From this he deduced that a cylindrical body makes a dark shadow at the distance of 38 to 45 diameters of that body; but when at a greater distance an illumination of the middle begins. Many other interesting experiments were made by Maraldi, which are still performed by students with intense interest.

It would be highly advantageous to recite the discoveries which have been made by Fresnel, Young, Arago, Fraunhofer, and others, but it would fill volumes to record the half. We cannot, however, but admire the wisdom and power of God, as it is displayed in the properties of the sublime fluid light, and his adorable benevolence in granting us capacity to investigate his works.

PART THE SEVENTH.

ON DOUBLE REFRACTION.

CHAPTER I.

On the Nature and Law of Double Refraction.

If a ray of light fall upon glass, vapour, or any fluid, the image formed is always single: or, in other words, when there is but one incident ray, there is only one refracted ray. But there are bodies, as the crystallized carbonate of lime, zircon, emerald, and many animal bodies, as horn, &c., which give two refracted angles, when there is only one incident ray. Bodies like the former are said to possess single refraction, and such as the latter double refraction.

Of the two refracted rays that which follows the ordinary law of refraction is denominated the ordinary ray, the other, the extraordinary ray. In all crystals which have double refraction, there is one line along which the double refraction vanishes; in some cases there are two lines. This line is called the axis of double refraction. Now when a ray of light is incident upon a body which has double refraction, the equal pencils make an angle with each other which varies according to the position of the incident ray, but when it strikes upon the line of the crystal of which we are speaking, the the two pencils coincide. Some crystals have two axes of double refraction, and it is worthy remark, that a ray transmitted along the axis, is always governed by the common law of single refraction.

In order to explain what is meant by the axes and fixed lines within a crystal, it is necessary to introduce a beautiful illustration from a paper on Light, inserted in the Encyclopedia Metropolitana. "Suppose a mass of brick work, of great magnitude, built of bricks all laid parallel to each other. Its exterior form may be what we please, a cube, or any other figure. We may cut it into any shape, but the edges of the bricks within it must still be parellel to each other; and their directions as well as those of the diagonals of their surfaces, or of their solid figures, may all be regarded as so many axes, i. e. lines having (so long as the mass remains at rest) a determinate direction in space, no way related to the exterior surfaces, which we may cut across the edges of the bricks in any angle we please. Whenever then we speak of fixed lines or axes of, or within a crystal, we always mean directions in space, parallel to each of a system of lines, drawn in the several elementary molecules of the crystals, according to given geometrical laws, and related in a given manner to the sides and angles of the molecules themselves."

When the extraordinary ray is refracted towards the axis of a crystal, that axis is called a positive axis, and when it is refracted, from it, the axis is denominated a negative axis.

All bodies crystallizing in the form of the rhomboid, the hexahedral prism, the octohedron with a square base, and the right prism with a square base, have double refraction. Now, in all these bodies, the ordinary ray has a constant index of refraction, whatever the inclination of the surface through which it enters may be, and its velocity, what direction soever it takes, is the same. But it is not so with the extraordinary ray, for its velocity depends on the angle it makes with the axis.

In order to discover the law regulating double refraction, Huygens measured the double refraction at different angles, and found that the reciprocal of the index of refraction of the extraordinary ray, was measured by an ellipse, whose lesser axis is to its greater, as $\frac{1}{1.6543}$ is to $\frac{1}{1.4833}$ reciprocals of the greatest and least indices of extraordinary refraction.

Abbè Haüy in his Traité de Mineralogie says, that the quantity of double refraction, or magnitude of the angle formed by the two rays, varies in different substances, all other things being similar, according to the nature of the substance. In zircon the double refraction is very strong, but it is much less than in the emerald. This quantity increases or decreases with the refracting angle, or that formed by the two faces through which you look.

Bartolinus, a physician of Copenhagen, who was the first who noticed double refraction in Iceland spar, after describing his experiments, accounts for the fact by supposing the crystal to have two sets of pores, one parallel to the direction of the sides, (for it may be observed, that according to the disposition of the sides, it is broken and its parts severed from each other,) and one like unto glass; through which a right image is transmitted. He supposes there are directions in which the rays pass the crystal unrefracted, and though in ordinary bodies their direction may be perpendicular to the surfaces, yet in other bodies they have other positions. He supposes half the incident pencil to be refracted usually, and the other half unusually.

Huygens, of whom we have had so much occasion to speak, added much weight to his theory of spherical waves, by his explanation of the phenomenon of double refraction. He conceived that the etherial matter exists in a greater quantity than the solid particles. Those spherical undulations which are propagated more slowly in the crystal than out, produce ordinary refraction. There is another set of undulations of an elliptical or spheroidal figure, and are propagated indifferently both in the etherial matter and solid particles. He considers also that the regular arrangement of the particles contributes to the formation of spheroidal waves as nothing more is required than that light should be propagated more quickly in one direction than in another.

We have already given Huygens' law for the velocity of the extraordinary ray, and it only remains to insert Haüy Table of bodies possessing double refraction.

Carb. of Lime, strong
Sulph. of Lime
Sulph. of Barytes
Sulph. of Strontian
Borat of Soda
Corundum

Euclase, strong
Feldspar
Peridot, strong
Mesotype
Sulphur, strong
Quartz

Zircon, very strong
Cymophane
Topaz
Emerald

Mellite
Carb. of Lead
Sulph. of Iron
Arragonite, strong.

To these many more might be added. Dr. Brewster has formed an important table of minerals, which possess double refraction, and has marked the positive and negative axis by the corresponding signs;—

—Carbon of Lime
—Carbon of Lime and Iron
—Carbon of Lime and Magnesia
—Carbon of Zinc
—Nitrate of Soda
—Phosphate of Lead
—Phosphato,—Arseniato of Lead
—Levyne
—Tourmaline
—Rubellite
—Ruby of Silver
—Alum Stone
+Dioptase
+Quartz

+Zircon
+Oxide of Tin
+Tungstate of Lime
—Mellite
—Molybdate of Lead
—Octohedrite
—Prussiate of Potash
+Titanite
—Idocrase
—Wernerite
—Paranthine

—Corundum
—Sapphire
—Ruby
—Cinnabar
—Arseniate of Copper

—Emerald
—Beryl
—Phosphate of Lime
—Nepheline
—Arseniate of Lead
+Hydrate of Magnesia

—Meionite
—Subphosphate of Potash
—Edingtonite
+Apophyllite of Uton
+Superacetate of Copper & Lime
—Phosphate of Ammonia and Magnesia
—Hydrate of Strontites
—Arseniate of Potash
—Sulphate of Nickel of Copper
—Somervillite
+Oxahverite.

Dr. Brewster has recently discovered that the greater number of crystals have two axes of double refraction, and that the axes form exceedingly varied angles with each other.

M. Fresnel to whom this branch of science is greatly indebted, has made the valuable discovery, that in crystals with two axes both rays follow the law of extraordinary refraction. But an occasion will be given in the next part to speak of this.

It is impossible in the limits of a short essay to speak of all the experiments Dr. Brewster has made, but among the most curious we may notice that when examing Glauberite he found two axes for the most refrangible rays, and one axis for the least refrangible rays.

PART THE EIGHTH.

ON POLARISATION OF LIGHT.

CHAPTER I.

Introductory Remarks.

"In all the properties and affections of light which we have hitherto considered," says Mr. Herschel, the learned author of a beautiful treatise on Light, to which we are in the following paper much indebted, "we have regarded it as presenting the same phenomena of reflection and transmission both as it respects the direction and intensity of the reflected or transmitted beam, however it may be presented to the reflecting or refracting surface, provided the angle of incidence and the plane in which it lies, be not varied. And this is true of light, in the state in which it is emitted immediately from the sun, or from other self luminous sources. A ray of such light incident at a given angle, on a given surface, may be conceived to revolve round an axis coincident with its own direction, or which comes to the same thing, the reflecting or refracting surfaces may be actually made to revolve round the ray as an axis, preserving the same relative situation to it in all other respects, and no change in the phenomena will be perceived. For instance, if in a long cylindrical tube we fix a plate of glass, or any other medium, at any angle of inclination to the axis, and then, directing the tube to the sun, turn the whole apparatus round on its axis, the intensity of the reflected or refracted ray will suffer no variation, and its direction (if deviated) will revolve uniformly round with the apparatus, so that if received on a screen, connected invariably with the tube, it will continue to fall on the very same point in all parts of its rotation."

But this is not the case with a ray which has been subjected to the action of bodies, as by reflection, and refraction, or in any other manner; for the intensity of that ray does then mainly depend on the position of its acquired sides with the plane of incidence; for all rays thus acted upon do acquire fixed sides, a right and a left, a front and a back, and is then, and therefore said to be, polarised.

But to make this definition more intelligible, let us take a plate of tourmaline, a mineral which generally occurs in prisms of six or more sides,* and it will be observed, when held before a candle, that in what direction soever it may be turned, the candle will be alike visible. Now, let this plate be held in some fixed position, and another plate be interposed between it and the eye, and turned slowly round in its own plane. The candle is no longer visible during the whole of its revolution, but alternately appears and disappears according to the position of the revolving plate with that which is fixed. Now, if the appearance and disappearance of the brightness be observed, it will be found greatest when the axes of the plates are parallel; this is called its maxima: it is least when the axes are crossed at right angles, this is called its minima. The experimentalist cannot have failed to observe, that the light which is transmitted through the first plate is emitted from a self-luminous body, but in passing through that plate has evidently acquired some new property.

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* Phillip's Mineralogy, p. 139.

It is not necessary to atttempt a refutation of those principles which are supported upon the phenomena of polarisation of light. The Lemma and Proposition given in Chapter II. of the First Part, we think substantiated by every discovery which has been made, and the theory consequently strengthened.

The above is a simple way of showing polarization by transmission, and is sufficient to define this remarkable branch of experimental inquiry.

CHAPTER II.

On the Polarisation of Light by Reflection.

To make the new property acquired by a reflected ray, evident by experiment, says the author of the beautiful Treatise on Light, from which we have before extracted, let any one lay down a large plate of glass on a black cloth, on a table before an open window, and placing himself conveniently so as to look obliquely at it, let him view the reflected light of the sky (or what is better, of the clouds, if not too dark) from the whole surface, which will thus appear pretty uniformly bright. Then let him close one eye, and apply before the other a plate of tormaline, so as to have its axis in a vertical plane. He will then observe the surface of the glass, instead of being as before equally illuminated, to have on it, as it were an obscure cloud, or a large blot, the middle of which is totally dark. If this be not seen at first, it will come into view on elevating or depressing the eye. If the inclination of a line drawn from the centre of the dark spot to the eye be measured, it will be found to make an angle of about 33° with the surface of the glass. If now, keeping the eye fixed on the spot, the tourmaline plate (which it is convenient to have set in a frame for such experiments) be turned slowly round in its own plane, the spot will grow less and less obscure, and when the axis of the tourmaline plate is parallel to the surface of the reflecting plate, (or horizontal) will have disappeared, so as to leave the surface equally illuminated, and on continuing the rotation of the tourmaline will appear and vanish alternately.

From this it would appear, that a ray reflected from glass is polarised at an inclination of 33°, when it becomes entirely incapable of second reflection; and from a variety of experiments founded on these facts, the following laws have been deduced.

1. That every reflective body is capable of polarising light, provided that light be incident upon it at a certain angle.

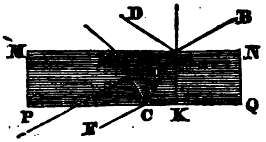
2. That different media vary in the angle at which they polarise light. The following Rule is given by Dr. Brewster for the determination of these angles. "The tangent of the polarising angle for any medium is the index of refraction belonging to that medium." There is but one case where this polarisation can be total, and that is when the incident ray is homogeneous, for when white light is incident, each ray is reflected at a different angle.

3. If the incident ray fall on a reflecting surface, or a medium capable of completely polarising it in a plane, perpendicular to that of the rays of polarisation, and at an angle of incidence equal to the polarising angle of the medium no portion whatever of it will be reflected.

From the law given by Dr. Brewster, the following propositions have been deduced. 1st, When a ray is reflected from a transparent surface, so that the reflected part is completely polarised, the supplement of the angle between the reflected and refracted rays is a right angle, and therefore the angle itself is a right angle.

2. When a ray of light falls at the polarising angle on a plate of a transparent medium, that portion of the ray reflected, from the second, as well as that reflected from the first surface is polarised.

This has been familiarily explainly in the following



manner. Let M N P Q, be a plate of glass, A B a ray incident on the first surface, at the polarising angle, A D the polarised ray, and A C the refracted ray, it is found by experiment, that the ray C M, reflected at the second surface, is polarised. In this case too, the angle M C F formed by the refracted and reflected ray is a right angle. For since D A C is a right angle, M N parallel to P C, and B A to C F, the angle F C P is equal to D A M, but M C P is equal to M A C: hence the whole M C F is equal to the whole D A C or a right angle.

The following mode of obtaining an intense polarised ray is generally used, viz., by a pile of parallel plates of glass placed on each other, for in this case, the light being reflected according to the last mentioned proposition, a strong polarised ray will be obtained. But it is, however, impossible that the polarised light should ever be more than one half the incident. A pile of window, or crown, glass has been recommended for this experiment, and may consist of about a dozen pieces, but plate glass is much better, for besides the irregularities to which crown glass is subject, the action of the atmosphere often causes it to seperate into thin films at the surface.

"If a ray be reflected at an angle, greater or less than the polarising angle, it is partially polarised, that is to say, when received at the polarising angle on another reflecting surface, which is made to revolve round the reflected ray, without altering its inclination towards it, the twice reflected ray never vanishes entirely, but undergoes alterations of brightness, and passes through states of maxima and minima, which are more completely marked, according to the angle, as the first reflection approaches nearer to that of complete polarisation. The same is observed when a ray so partially polarised is received on a tourmaline plate revolving as above described in its own plane. It never undergoes complete extinction, but the transmitted portion passes through alternate maxima and minima of intensity, and the approach to complete extinction is the nearer the nearer the angle of reflection has been to the polarising angle."

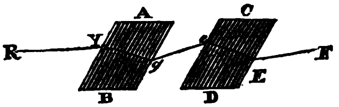
CHAPTER III.

The Polarisation of Light by common Refraction, and its Laws.

If a ray of light be incident on a plate of glass, inclined to the direction of the ray, when transmitted, it is found to be partly polarised at right angles to the plane of refraction. Moreover it has been discovered by M. Arago, that if a polarised ray is partly reflected and partly transmitted through a transparent surface, the reflected and transmitted pencils contain equal quantities of polarised light, and their planes of polarisation are at right angles to each other. This, therefore, establishes the identity of polarisation by reflection and refraction.

If a bundle of glass plates be so exposed to a polarised ray, that the angle of incidence and the polarising angle be equal, it will be found that the whole of the incident ray is transmitted when the plane of incidence is at right angles to the plane of the rays of polarisation.

Let A B, C D be two bundles of glass plates which are so placed that their planes of refraction are equal. Let R Y be a ray of light, which is polarized at *y*, and penetrates C D at *e*, not any portion of it shall be re-



flected by the plates of C D. If C D be turned on its axis, E F will gradually diminish: the light which is incident on C D will become more and more reflected, and after a rotation of 90° the whole of the ray will be reflected, and E F will of course vanish.*

Dr. Brewster gives the following law in the case of imperfect polarisation. If a pencil of light be incident on a number of uncrystallized plates inclined at the same or different angles, but all their surfaces being perpendicular to the plane of the first incidence, the total polarisation of the transmitted pencil will commence when the sum of the tangents of the angles of incidence on each plate is equal to a certain constant quantity due to the refractive power of the plates, and the intensity of the incident ray.

When the plane of incidence is at right angles to that of the ray's polarisation, the whole of the incident light is transmitted, its polarisation being unaltered. But as the pile revolves round the incident ray, the light is reflected, and this increases till the plane of incidence is coincident with the plane of primitive polarisation, when the reflected light is a maximum.

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* See Polarisation of Light. Sub. U. Knowledge, p. 13.

CHAPTER IV.

On the Polarisation of Light by Double Refraction.

If a ray of light be divided into two pencils by transmission through a double refracting medium, and these pencils be kept distinct at their emergence, it will be found that they are both polarised in planes at right angles to each other.

Take a plate of glass and lay it upon a black cloth before an open window, then take a rhomboid of Iceland spar and cover it on one side with some thin opaque substance, in which make a small hole, present the covered side to the reflected surface from the glass, and you will observe two images of the hole you made in the substance which covers the spar, which are of unequal intensity. Now turn the rhomboid in the plane of the covered sides, and the images will vary in relative brightness: when the ordinary ray is a maximum, the extraordinary will be a minimum, and vice versâ.

Huygens discovered the opposite polarisation of the two pencils, which are formed by double refraction; and described the phenomena in his Treatise on Double Refraction. Take two rhombs of Iceland spar, and lay them together with their homologous sides parallel, so that light may be transmitted through them as though they were one. Now lay them on a sheet of white paper, which has a small spot distinctly marked on it, and the spot will be seen double. Turn the upper crystal upon the other and two new images will appear, which increase in brightuess while the former decrease, until the upper crystal forms an angle of 90°, when the original images disappear. If the rotation be continued the evanescent images will again appear and increase, while the others decrease; and, at the half revolution, the original images unite, and the others become evanescent. In this case only single refraction happens; or rather the double refraction of the two rhomboids taking place in opposite directions, and being equal in amount compensate each other, but in order to do this the rhomboids must be exactly of equal thickness!

"The property of a double refraction, in virtue of which a polarised ray is unequally divided between the two images, furnishes us with a most useful and convenient instrument for the detection of polarisation, in a beam of light, and for a variety of optical experiments. It is nothing more that a prism of a doubly refracting medium, rendered achromatic by one of glass, or still better by another prism of the same medium, properly disposed, so as to increase the seperation of the two pencils. The former method is simple, and when large refracting angles are notwanted, the unconnected colour in one of the images is so small as not to be troublesome, and may therefore be neglected without correction. It is most convenient to make the refracting angle such as to produce an angular seperation of about 2° between the two images."

CHAPTER V.

On the Colours exhibited by crystalised plates, when exposed to polarised light, and of the polarised rays surrounding their optic axes.

Place a polished surface of large extent, as a well polished mahogany table, near an open window, as in the former experiments; then take a mica plate, about one thirtieth of an inch thick, and place it between the eye and the polished surface as near the polarising angle as possible. Nothing particular will be observed from this arrangement until the experimentalist takes a tourmaline plate, and looks through it, and it will be observed, when the axis is vertical, that the surface is beautifully illuminated with the most splendid colours. But if the mica plate be taken away, the reflected beam will be destroyed by the tourmaline, and the polished surface will become dark. There are two positions in which all colour disappears, which will be discovered if the mica plate be held perpendicular to the reflected beam, and turned on its own axis.

The colours which are thus shown are proportional to the thickness of the plates, if the mica be less than one thirtieth of an inch, they will be more vivid, if of greater thickness they will decrease, until at last they disappear.

Take the mica plate used in the last experiment, and draw on it, with a steel point, two lines corresponding to the intersections of the mica, with a vertical plane passing through the eye in either of these positions, and they will make an exact right angle; call these lines A and B, and let a plane drawn through A be called the section A, and another through B, be called the section B. Then when we turn the plate so that the section A and B make an angle of 45°, with the plane of reflection, the transmitted light will be a maximum. The section A is characterized by two very remarkable lines inclined at equal angles to the plate, which are possessed of this property, that whatever be the plane of polarisation of a ray, incident along either of them, it remains unaltered after transmission. These positions of the optic axes, as these lines have been denominated, is $22\frac{1}{2}$° inclined to the perpendicular, and the angle between them is 45°.

If the mica plate be inclined to the polarised beam of light so that the latter shall be transmitted along the optic axes, the section A making an angle of 45° with the plane of polarisation, and the eye covered with the tourmaline plate, applied close to the mica, the black spot in the direction of the optic axis will be seen surrounded with a set of coloured rays, of an oval form, divided into two parts by a black stroke, which passes through the angular situation of the optic axis, round which the rings form as round a centre. Its convexity is turned towards the direction of the other axes, and on that side the rings are also broader. But when the other axis is brought into a similar position, a phenomenon, exactly similar is seen surrounding its place as a pole. If the plate of mica be thick the two sets of rings appear entirely seperate from each other, each ring being narrow and close, but when it is thin, then each ring is much broader, and especially so in the interval between the poles, so that they entirely lose their elliptic appearance, and dilating towards the middle into a broad coloured space. If the mica plate be turned round the visual axis, the black band passing through the pole will shift its place, and revolving on the pole, as on a centre with double the angle of velocity, will successively obliterate every part of the rings.

With regard to the form of the rings, when they are projected into a darkened room, on a screen and traced with a pencil upon it, they have a complete resemblance to the curve denominated lemniscate, and may be compared with a system of lemniscates, when the coincidence of the curves with these rings will be found, and the magnitude of the rings will be discovered to vary inversely, as the thickness of the plates of mica through which the light passes.

The colours of the polarised rings (says the author of the paper to which we are obligated so much) bear a great analogy to those reflected by thin plates of air, and in most crystals would be precisely similar to them but for a cause presently to be noticed. In the situation of the tourmaline plates here supposed (crossed at right angles) they are those of the reflected rings, beginning with a black centre at the hole. If examined, and traced in a line from either pole, cutting across the whole system at right angles to the lines joining the poles, they will almost precisely follow the Newtonian order of tints. For the present we will suppose that they do so in all directions. It is evident, then, that each particular tint (as the bright green of the third order for instance) will be disposed in the form of a lemniscate, and will have its own particular value of the product $a\ b$. In conformity with this language the coloured curves have been termed and not inaptly isochromatic lines. Now in the colours of thin plates we have seen that these tints arise from a law of periodicity, to which each homogeneous ray is subject, and that without entering at this moment into the cause of such periods, the successive maxima and minima of each particular coloured ray, passes through in the scale of tints, correspond to successive multiples, $\frac{1}{2}$, $\frac{2}{2}$, $\frac{3}{2}$, $\frac{4}{2}$, &c. of the period peculiar to that colour. In the colours of thin plates the quantity which determines the number of periods is the thickness of each plate of air or other medium traversed, and the number of times a certain standard thickness peculiar to each ray is contained therein, determines the number of periods or parts of a period passed through. In the colours and in the case now under consideration, the number of periods is proportional to the product $(\theta \times \theta')$ of the distances from each pole for one and the same thickness of plate, and for different plates to t, the thickness, and therefore generally to $\theta \times \theta' \times t$, provided we neglect the effect of the inclination of the ray, in increasing the length of the path of the rays within the crystal, or regard the whole system of rings as confined within very narrow limits of incidence.

This condition obtains in the case here considered, (a case in which nitre is used instead of a plate of mica,) because of the proximity of the axes in nitre to each other, and to the perpendicular to the surfaces to the plate. But in crystals, such as mica or others, where they are still wider asunder it is not so, and the projection of the isochromatic curves on a plane surface will deviate materially from their true form, which ought to be regarded as delineated on a sphere, having the eye, or rather a point within the crystal, for a centre. In such a case, it might be expected that the usual transition from the arc to its sine, would take place, and that instead of supposing the tint, or the value *a b* to be proportional, simply to $\theta \times \theta' \times t$, we ought to have it proportional to sine $\theta \times$ sine $\theta' \times$, length of the path of the ray, within the crystal. Now, (putting ρ for the angle of refraction, and t for the thickness of the plate) we have t sec. ρ,—length of the ray's path within the crystal. If then we put n for the number of periods corresponding to the tint *a b*, for the ray in question, and suppose $h = \frac{ab}{n}$, or the unit whose multiples determine the order of the rings, we shall have

$$n = \frac{ab}{h} = \frac{t}{h} \text{ sin. } \theta, \text{ sin. } \theta', \text{ sec. } \rho,$$
$$\text{and } h = \frac{t}{n \cos \rho} \text{ sin. } \theta, \text{ sin. } \theta'.$$

If then the suppositions be correct, we ought to have the functions of the right hand side of the last equation invariable, in whatever direction the ray penetrates the crystallized plate, and whatever be the order of the tint denoted by n, aud this is completely established by experiment.

If the crystal be uniaxial (the two axes having coalesced) the lemniscate curves become circles, the black bands being straight lines, situated at right angles to each other. But the forms of these rings are only regularly discribed in perfect and clear crystals. If a crystal contain any extraneous matter, or if the structure of it has been disturbed by outward causes, the form both of the rings, and the cross is broken and irregular.

"All crystals, whether with one or two axes, in which the rings or lemniscates formed are of small magnitude, in respect of the thickness of the plate producing them, are powerfully doubly refractive, and vice versâ, and that generally speaking, the seperation of the ordinary and extraordinary rays is, cæteris paribus, greater in proportion as the rings are more close and crowded round their poles. This is easily verified by experiment, showing that there must be some connection between the power producing double refraction, and the power producing the rings, as well as between the rings produced by polarised light, and those produced by interference. Future experiments no doubt will add their approving testimony. The theories and doctrines of light, like all others, are but in their infancy, every day bringing fresh accumulation to the knowledge already acquired, and one discovery is so linked on to another which must follow it, that the attentive mind must always perceive something new and imposing on the announcement of a fresh discovery, perhaps ere long some happy thought may show that reflection, refraction, inflection, and polarisation, with all their minor varieties and modifications are owing but to one cause, surpassingly simple in its operations and circumstances."

Having attempted a very brief description of the more prominent parts of Polarisation of Light, we would warmly recommend the reader who may be roused into inquiry concerning this interesting study, to examine Mr. Hershel's treatise to which this paper is indebted, on the subject, for it is among the finest philosophical productions of this country.

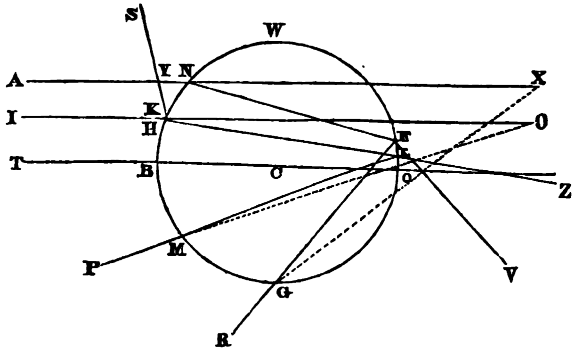
PART THE NINTH.

ON THE APPLICATION
OF THE
PRECEDING FACTS, AND THEORIES TO NATURAL PHENOMENA.

Of all the natural appearances connected with Optics, the most common as well as the most beautiful is that of the rainbow. In times past there must have been theories invented for its explanation, of which no remnant is now left. Maurolycus is the first on record, who pretends to have made any observations on it. Baptista Porta imagined the rainbow to be produced by refraction from the whole body of rain, and not in the separate drops. Antonio de Dominis at last hit upon the truth. As far as he went he was perfectly correct, but he could neither account for their being any colour, nor for the external bow, so Newton completed what Antonio attempted.

" Let the circle W Q G B represent a drop or globe of water, upon which a beam of parallel light falls, and of which let T B represent a ray, falling perpendicularly at B, and which by consequence either passes through without refraction, or is reflected back from

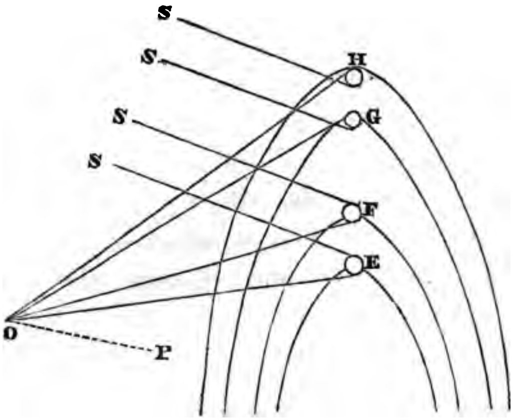
Q. Suppose another ray IK, incident at K, at a distance from B, and it will be refracted, according to a certain



ratio of the sines of incidence, and refraction to each other, (which in rain water is as 529 to 396,) to a point L, whence it will be in part transmitted in the direction L Z, and in part reflected to M; where it will be again reflected, and in part transmitted in the direction M P, being inclined to the line described by the incident ray in the angle I O P. Another ray A N still further from B, and consequently incident under a greater angle, will be refracted to a point F, yet farther from Q, whence it will be in part reflected to G, from which place it will in part emerge, forming an angle A X R, with the incident ray A N greater than that which was formed between the ray M P and its incident ray. And thus while the angle of incidence or distance of the point of incidence from B increases, the distance between the point of reflection and Q, and the angle formed between the incident and emergent reflected rays will also increase, that is to say, so far as it depends on that increase of incidence. But as the refraction of the ray tends to carry the point of reflection towards Q, and to diminish the angle formed the incident and emergent reflected ray, and that the more, the greater the distance of the point of incidence from B, there will be a certain point of incidence between B and W, with which the greatest possible distance between the point of reflection and Q, and the greatest possible angle between the incident and emergent reflected ray will correspond, so that a ray incident nearer to B, shall at its emergence, after reflection, form a less angle with the incident by reason of its more direct reflection from a point nearer to Q, and a ray incident nearer to W, shall at its emergence form a less angle with the incident, by reason of the greater quantity of the angles of refraction at its incidence and emergence. The rays which fall in the vicinity of that point of incidence with which the greatest angle of emergence corresponds, will, after emerging from an angle with the incident rays, which differs insensibly from that greatest angle, and consequently will proceed nearly parallel to each other, and those rays which fall at a distance from that point, will emerge at various angles, and consequently diverge. Now to a spectator whose back is turned towards the radiant body, and whose eye is at a considerable distance from the globe, or drop, the divergent light, will be scarcely, if at all, perceptible, but if the globe be so situated that those rays which emerge parallel to each other, or at the greatest possible angle with the incident may arrive at the eye of the spectator, he will by means of those rays behold it nearly with the same splendor at any distance."

The quantity of this greatest angle is determined by calculation, the proportion of the sines of incidence and refraction to each other being known. And this proportion being different in rays which produce different colours, the angle must vary in each.

Thus it is found that its limit in rain water for the least refrangible or red rays, emitted parallel after one reflection, is 42° 2′ and for the most refrangible 40° 17′ likewise after two reflections the least refrangible will be emitted most copiously under an angle of 50° 57′, and the violet under 54° 7′. The intermediate colours will be most copiously emitted at intermediate angles.



Suppose that O is the spectator's eye, and O P a line drawn parallel to the sun's rays, and let P O E, POF, POG, POH, be angles of 40° 17′, 42° 2′, 50° 57′, and 54° 7′, respectively and these langes turned about their common side OP, shall with their other sides describe the verges of two rainbows, as in the figure. For if E, F, G, H, be drops placed any where in the conical superfices described by O E, O F, O G, O H, and be illuminated by the sun's rays S E, S F, S G, S H, the angle S E O, being equal to P O E, or 40° 17′, shall be the greatest angle in which the most refrangible rays can after one reflection be refracted to the eye, and therefore all the drops in the line O E shall send the most refrangible rays most copiously to the eye, and thereby strike the senses with the deepest violet colour in that region. And in like manner, the angle S F O being equal to the angle P O F, or 42° 2′, shall be the greatest in which the least refrangible rays after one reflection can emerge out of the drops, and therefore those rays shall come more copiously to the eye from the drops in the line O F, and strike the senses with the deepest red colour in that region. And in the same manner the rays in the intermediate degrees of refrangibility shall come most copiously from the drops between E and F, and strike the senses with the intermediate colours in the order which their degrees of refrangibility require, that is in progress from E to F, or from the inside of the bow to the outside, in this order, violet, indigo, blue, green, yellow, orange, red. But the violet by the mixture of the white light of the clouds will appear faint and inclined to purple.

Again the angle S G O being equal to the angle P O G, or 50°, 51′, shall be the least angle in which the least refrangible rays can after two reflections emerge out of the drops, and therefore the least refrangible rays shall come most copiously to the eye, from the drops in the line O G, and strike the sense with the deepest red in that region. And the angle S H O being equal to the angle P O H, or 54° 7′, shall be the least angle, in which the most refrangible rays after two reflections can emerge out of the drops, and therefore those rays shall come most copiously to the eye from the drops in the line O H, and strike the senses with the deepest violet in that region, and by the same argument the drops in the region between G and H shall strike the sense with the intermediate colours, in the order which their degrees of refrangibility require. And since the four lines O E, O F, O G, O H, may be situated any where in the above mentioned conical superfices; what is said of these drops and colours must be understood of the drops and colours every where in those superfices."

Thus then there are two bows, an interior and stronger by one reflection, and an exterior and fainter caused by two reflections, whose colours are therefore in the contrary order to the first.

Halos, parhelia, &c., are optical phenomena, produced by reflections and refractions but in what manner is not exactlya greed among philosophers. Various hypotheses have been advanced, each of which has its advantages and defects.

The apparent distance of objects is chiefly deduced in the mind from a comparison of the magnitude of objects with their brightness. Now, if we see two windmills, one of which is larger than the other, the smaller being a little the nearer to us, we often suppose, when standing a short distance from them, that the small one is the larger. Such deceptions of the mind are very frequent, and for another instance it may be remarked, that when ardently gazing on the moving sails of a distant mill, we fancy them to turn an opposite way to that in which they actually move. The deception when on board a ship in motion is very striking, for then every thing around us appears to move, but we ourselves to be stationary. If we look steadfastly at a seal on which any letters are engraved they often appear to rise from their concavity, and project in releif, the mind being deluded by the position of their shadows.

The concave figure of the sky is produced by an optical appearance easily accounted for, for the sky and earth must at a distance seem to approach each other, and the space between them must appear less and less until they meet. But as this must occur all round in every point the sky must therefore appear a deep conçave.

The beautiful colours of the soap bubble have frequently amused us during infancy, they are produced on the principle of the assumption of colour by thin plates of any substance. This bubble was of eminent use to Sir Isaac Newton in the study of Chromatics for by its assistance he discovered his Theory of Colours. Sometimes after a shower on a summer's afternoon, we see on the cabbage leaves drops of rain of beautiful resplendence, and this is produced by a copious reflection from the under side of the drop, which is flattened by its near approach to the leaf, for it does not touch it, but is kept at a small distance from it by a repulsive energy, which is exerted so soon as it comes in contact, the light passes through it and the reflection ceases.

If we look steadfastly at a window through which a strong light passes, and then close our eyes, the impression is still left, and we distinctly perceive the divisions and every part of it, almost as plainly as if our eyes were open, this is produced by the vibrations of the optic nerve which still continue without being disturbed by any new objects.

The cameleon is an animal which can, as is well known, change the colour of his skin to various shades, and this it does by altering its outward texture, and causing it to reflect this or that colour by such changes.

PART THE TENTH.

ON OPTICAL INSTRUMENTS.

CHAPTER I.

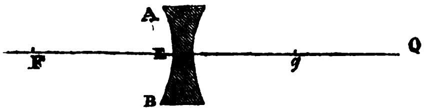
Spectacles are the most simple of all optical instruments. They were well known in the thirteenth century, but it cannot be ascertained who invented them. On the tomb of Salvinus Armatus a nobleman of Florence, who died in 1317, it is asserted that he was the inventor; what right he has to the honour we cannot determine. If it be admitted that the real value of a discovery consists in alleviating the bodily misfortunes of mankind, this invention is the most valuable we are acquainted with.

It has been already stated that the crystalline lens of the eye refracts the light which proceeds from the objects before it and that the images of such objects are received at the focus of the eye on the retina, by which the sensation of vision is conveyed to the mind. Now it must appear evident that when the retina is not the focus of the crystalline lens of the eye, an imperfect vision must be the consequence.

When the convexity of the eye is lessened by age, the image must, by the laws of refraction, be thrown beyond the retina, therefore the vision will be indistinct. This defect may be corrected by the use of a suitable convex glass; for the rays of light, by passing through the glass, are refracted at a shorter focus, and a perfect vision is restored. Near sightedness, on the other hand, arises from a too great convexity of the eye, and on that account the focus of the eye is not far enough to reach the retina, and must therefore be corrected with a concave glass.

The following Problems may be considered as including almost every thing connected with the theory of spectacles. They are thus demonstrated by Mr. Barlow.

Prob. I. Given the distance at which a short sighted person can see distinctly, to find the focal length of a glass which will enable him to see at any other given distance.



Let E*g* be the distance at which he can see distinctly, and Q E a greater distance, at which he wishes to view objects; let A B be a concave lens, whose focal length is such, that the rays which are incident upon it, diverging from Q, may, after refraction, diverge from *g*; then they will have a proper degree of convergency for the eyes of the myope.

Take F, the principal focus of rays incident on the contrary direction; then

$$QF : QE : QE : Qg,$$

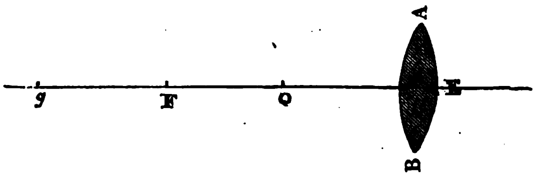
consequently,

$$QF - QE : QE :: QE - Qg : Qg,$$

whence, $FE = \frac{QE \times Eg.}{Qg.}$

If QE be indefinitely great, then $QE = QF$, and $FE = Eg$.

Prob. II. Having given the distance at which a long sighted person can see distinctly; to find the focal length of a convex lense, which will enable him to see distinctly at any other distance.



If gE be the distance at which he can see distinctly, and QE the distance at which he wishes to view objects, and AB be a convex lense, whose focal length FE is such that the rays which diverge from Q, may after refraction diverge from g. Take F the principal focus of rays incident in the contrary direction, then, as above,

$$QF : QE : QE : Qg,$$

consequently,

$$QF + QE : QE :: QE + Qg : Qg$$

whence, $FF = \frac{QE \times Eg.}{Qg.}$

If Eg be indefinitely great, or the eye require parallel rays, then $Eg = Qg$, and $FE = QE$.

CHAPTER II.

On Telescopes.

The telescope is an instrument which is used for viewing distant objects, and a magnified representation is effected by increasing the apparent angle under which the object is seen. This instrument was not discovered till the sixteenth century, and who invented it is a matter of great dispute. Des Cartes supposes James Metius to be the inventor. Some persons attribute the discovery to the children of Lippersheim, a spectacle maker at Middleburgh, and others to Galileo. Borellus, in his De vero Telescopii Inventore, attributes the discovery to Joannides.

Telescopes are of two kinds, refracting and reflecting; of which there are many varieties. The refracting telescope has been greatly improved; for, since the invention, much attention has been directed to it, under the hope of bringing it to a state of perfection. The first telescope which the celebrated Galileo made, magnified only three times, and that with which he discovered the satellites of Jupiter thirty-three times. But many philosophers have, since his day, contributed to increase the importance of this instrument.

Dioptric or refracting telescopes are of three kinds, viz., the Galilean, the Astronomical, and the Terrestial.

The Galilean telescope is supposed to have been invented by the philosopher whose name it bears, in the year 1609. It has only two glasses; the eye lense being concave, or plano-concave, and situated between the object glass and its focus, in such a manner that the axes of the glasses may be in the same right line, and the foci in the same point.

The greatest objection to this instrument is its confined field of vision, which arises from the smallness of the lenses preventing many of the rays which proceed from an object entering the eye. Nor is it possible to enlarge the field; for the objects viewed, are not, as in convex glasses, as the area of the lense, but as the area of the eye. This great objection soon induced astronomers to seek a more effective instrument; but the construction is still employed for opera glasses, and as it forms a more distinct image than any other arrangement, it is particularly adapted for the purpose. Its distinctness arises from the rays of light passing through the lenses without crossing.

The Astronomical Telescope, like the Galilean, consists of two lenses; but the eye-glass is convex, or plano-convex, and the object glass convex. These lenses must be so placed that their foci may coincide in the axis of the tube, or in other words, they must be placed at a distance equal to the sum of their foci. The magnifying power of this instrument may be found by dividing the focal length of the object glass by that of the eye glass.

On account of the image of an object being inverted in this telescope, it is only used for astronomical purposes, but by the addition of two convex glasses of the same power, as the eye lense, and fixed at a distance from each other equal to the sum of their foci, the image is erected, and a terrestial telescope formed.

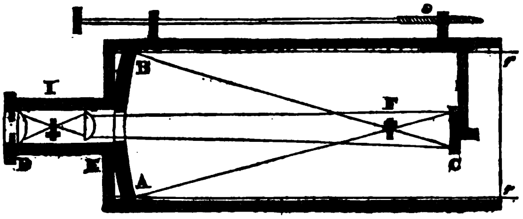
" The properties of this instrument," says Mr. Barlow, "are analogous to those of the astronomical telescope; but for terrestrial observations it is much more pleasant, on account of its preserving the direct position of objects; whereas the latter, is better suited to astronomical purposes, because it admits of a larger field of view, will carry an eye-glass of a shorter focus, and may be shorter in proportion to its diameter. There will, moreover, be less light lost by two than by four refractions."

Catoptric, or Reflecting Telescopes, are of three kinds, and are distinguished by the names of their inventors, and it may not be improper to describe them in the order of their discovery.

The Gregorian Telescope was invented by Mr. James Gregory, when a student at Glasgow. Dr. Pringle, however, informs us that Mersennus was the first who thought of a reflecting telescope; but it must surely be undeniable that Gregory was the discoverer. From the detracting manner in which some writers speak of Gregory's claim, it would appear they had little disposition to award him the honour his uncommon philosophical genius demanded, perhaps on account of his youth. But although this instrument was discovered six years before the Newtonian, it was not constructed until some years after Sir Isaac had erected his six inch reflector. It is now in general use, and is greatly preferred to the Newtonian; because the observer looks immediately at the object, whereas in the latter he stands at right angles to it.

Let figure 1 be a Gregorian Telescope, A.B is a concave mirror, formed by the revolution of the hyperbolic curve, and in it a small hole which must necessarily be in the centre. C is a smaller mirror, concave elliptical, which is placed in the axis of the larger, and stands at

Fig. 1.



a little more than the sum of their focal distances from it. D and E are the eye lenses, which are plano-convex. The adjustment is made by the screw, *s*, which moves the small mirror to or from the larger. Let the rays, *r r*, emenate from any object, striking the larger spectrum, A B, from which they are reflected, converging and crossing each other in F form an inverted image of the object which afterwards falls on the small spectrum, C. From this they are reflected, converging and passing through the aperture in the great mirror through the lenses into the eye.

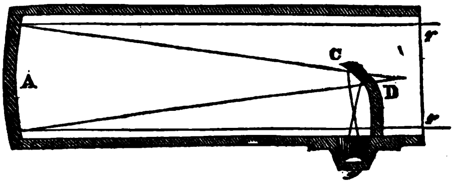
The magnifying power of this telescope may be found by multiplying the focal distance of the great mirror, by the distance of the small mirror from the image lens; then multiply the focal distance of the small mirror by the focal distance of the eye glass, and by dividing the former product by the latter, the magnifying power will be found in the resulting quotient.

The Cassegrainian reflector is no unimportant improvement to this telescope, and is, according to Mr. Ramsden, who has published a paper on the subject, in the sixty-ninth volume of the Philosophical Transactions, preferable to either of the reflectors used before it; the mirrors having a mutual tendency to correct each other. The Cassegrainian reflector is convex-spherical, and the focus being negative is placed at a distance from the larger mirror equal to their foci.

The Newtonian telescope is seldom used for an instrument less than five feet. It consists of a parabolic speculum, on and from which the rays are reflected, as in the Gregorian telescope; but being intercepted by a small plane mirror, are bent at an angle, formed with the axis of the tube, of 45°, before they unite in a focus, and the rays are reflected towards the side of the tube, and are seen through the medium of an eye glass.

Let Figure 2, be a Newtonian Telescope; A is the concave parabolic mirror, C is the plane mirror fastened to the arm D, which is connected with the eye-piece, *g*. This is now made to slide; but would it not be adjusted better if connected with a screw, as in the Gregorian reflector? The eye-glass is a single lens, with its flat side outermost, and is called the astronomical eye-piece. On account of the colour produced by these lenses, the negative achromatic eye lense is generally added to the plano convex. But Dr. Brewster has recommended the use of two glass prisms instead of the eye glass, which is found highly advantageous.

Fig. 2.



This telescope has been much improved since its discovery, but the most important alteration was that made by its celebrated inventor. The first telescope which Sir Isaac made was with a spherical concave large mirror, but he afterwards ascertained that, by giving it a parabolic shape, no spherical aberration could be produced.

The power of this instrument may be ascertained by dividing the focus of the great mirror by that of the eye glass.

The third kind of reflecting telescope is that of Hershel's, which he called the Front View Telescope. This is only used when a very large field is required, but enjoys many advantages over the Gregorian and Newtonian; particularly in that it has no small mirror, and the image is viewed directly from the great mirror, by means of an eye glass. The largest telescope of this kind in the country, is that at the Royal Observatory, now under the care of that great Astronomer Mr. Pond, of whom we shall have much occasion to speak in the Treatise on Astronomy.

Since the discovery of reflecting telescopes, a method of constructing object glasses, which are free from chromatic error and spherical aberration, has been found. These were called, on that account, achromatic glasses; but Sir W. Herschel has very properly named them aplanatic, from the two Greek words, *α*, without, *πλανος*, error.

If two lenses be formed of different substances, the length of the spectrum is found to vary considerably. Now, for instance, let two lenses of the same focal distance be formed, one of crown glass, the other of flint, and it will be observed, that the proportion between the red and violet rays in the flint, will be to that of the crown, as 3 to 2. It is evident then, that to make the spectrum, produced by them equal, we must make the focal length of the lenses in that proportion. "But if the flint lens be concave, and the crown convex when placed in contact they will mutually correct each other, and a pencil of white light refracted by the compound lens, would remain colourless."

CHAPTER III.

On Mircrometers.

The connexion of the Micrometer with the Telescope seems to point out this place as suitable for a few remarks on its construction and use. The rapid advances which Astronomy has of late made towards perfection, may, in a great measure, be attributed to the invention of the Micrometer; for the Telescope of itself would be insufficient for the observations which have been made, and was not able, separated from this instrument, to effect any important changes in the celestial science. If we know any thing accurately of the revolution of planets, their distances or figures; if we have discovered the successive propagation of light, and thus demonstrated its materiality; if we have examined the transits of bodies, and if our observations are corrected by the discovery of aberration; to these instruments, so inseparably connected, we are indebted for all.

The Micrometer is an instrument which is applied to Telescopes and Microscopes for the measurement of small bodies, or angles, subtended by distant bodies. The common wire Micrometer, which was usually attached to the eye piece of Telescopes, consists of two parallel wires, and by opening or shutting these wires, which is done by a mechanical contrivance, the angle subtended by any small space is measured. It is not necessary to describe at large this instrument, for it is liable to numerous errors from which others are exempt.

" The difficulty of finding the real zero of the scale, or the instant when the two wires appear to be in contact; the error arising from the want of parallelism in the wires, or from a lateral shake of the forks which carry them; the inflexion of light which takes place when the wires are near each other; the complicated structure of the instrument; the minuteness of the scale, and of all its parts; but especially the difficulty of procuring screws, in which the distance of the threads is always the same, are objections inseparable from the construction of this instrument."*

The new wire Micrometer consists of two fixed parallel wires, which are placed in the focus of the eye glass, across the field of view. By varying the magnifying power of the Telescope to which the Micrometer is fixed, the image of any body under examination may be dilated or lessened, and the angle, subtended by it, measured.

The magnifying power of a Telescope may be gradually changed by altering the distance between the two parts of the achromatic eye glass; " or by making a convex, a concave, or a meniscus lens move along the axis of the Telescope, between the object glass and its principal focus."

The last of these contrivances Dr. Brewster considers preferable. Let O be the object glass whose principal focus is at *f*, we use the Doctor's description, and L be the separate lens which is moveable between O and *f*. The parallel rays, R R, converging to *f*, after refraction by the object glass O, are intercepted by the lens L, and made to converge to a point F, where

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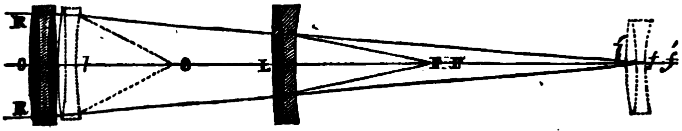
* The curious reader may see a short but accurate description of this instrument in Brewster's Treatise on Philosophical Instruments.



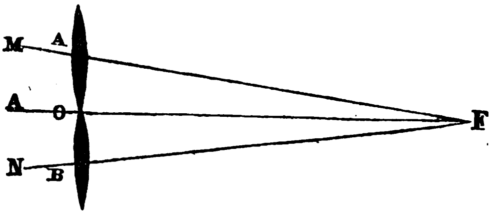
they form an image of the object from which they proceed. The focal distance of the object glass, O, has therefore been diminished by the interposition of the lens, L, and consequently the magnifying power of the Telescope; and the angle subtended by the pair of fixed wires in the eye-piece have suffered a corresponding change. When the lense is at *l*, in contact with the object glass, the focus of parallel rays will be about ϕ; the magnifying power will be the least possible, and the angle of the wires will be a maximum; and when the lense is at *l*, so that its distance from O is equal to O*f*, the focus of parallel rays will be at *f*;—the magnifying power will be the greatest possible, and the angle of the wires a minimum.

But L has many intermediate positions that must be ascertained, which can only be done by experiment. The value of these positions can, however, be easily determined; the minimum and maximum being known.

Upon the same principle we may construct a Micrometer for the Gregorian and Cassegrainian Telescopes. It is a principle of these instruments that their magnifying power may be varied, by an alteration of the distance between the large mirror and eye piece. Then, if you insert parallel wires in the eye-piece, any angle may be measured by altering the distance of the eye-piece, and adjusting the small mirror, and may be read off, a scale being experimentally formed.

The divided object glass Micrometer consists of of two semilenses of the same focal length which act as two distinct glasses. " The centres of these semilenses are made to separate and approach each other by means of a screw or pinion, and the distance of their centres is measured upon a scale subdivided by a vernier.

" It is required to measure the angle subtended by two objects M N, the semilenses are separated till the two images of these objects are in contact, or till the image of M, formed by the semilens A, appears to be in contact with the image of N, formed by the semilens B. When this happens the angle subtended by the objects is equal to the angle subtended by A B, the distance of the centres of the semilenses at the point F, or the focus of the lenses where the contact of the images takes place. It is manifest that an image of M will be formed in the line A F, and at F, the focus of rays diverging from M. In like manner an image of N will be formed in the line B F, and at F the focus of rays proceeding from the radiant point N. Hence it is obvious that the angle subtended at F by M N is the same as the angle sub-



tended by A B at F. The angle, A F B, may easily be found trigonometrically, the sides A B and O F being known; but as this angle is generally very small, it may, without any perceptible error, be considered as proportional to the subtense A B, or the distance between the centres of the semilenses. By determining, therefore, experimentally, the angle which corresponds to any distance A B of the semilenses, we may, by simple proportion, find the angle for any other distance."

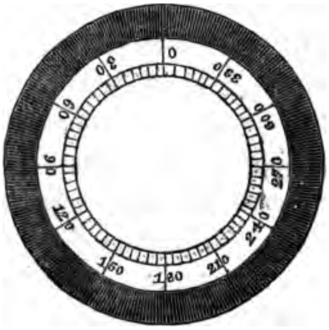
Dr. Brewster improved this instrument by fixing the semilenses at a certain distance from each other, yet susceptible of movement between the eye piece and object glass which he fixed in the usual manner. By this means the magnifying power of a Telescope could be changed; and by fixing a graduated scale to the Telescope the angle may be read.

A few remarks may be appropriate on the circular Micrometers. Dr. Brewster has entered at large into a description of these instruments and a consideration of their comparative merits in his Treatise on New Philosophical Instruments, from which work we took the above extract.

The Mother of Pearl Micrometer was invented by Cavallo, and was described by him in the Philosophical Transactions for 1791. It consists of a strip of Pearl minutely divided, and stretched across the diaphragm, which is placed in the anterior focus of the first eye glass of a Telescope. The angle subtended by any object may be determined by the number of divisions that object occupies; the value of the divisions being previously ascertained by experiment.

Although this instrument is exceedingly convenient for some portable Telescopes, it has many disadvantages. One irremediable objection is, that, by stretching across the centre of the field of view, it obstructs and divides the image. Another disadvantage is that, the different divisions of the instrument are at unequal distances from the eye glass, and therefore create error. Moreover, the edge of the Micromoter always requires to be in the direction of the object to be measured; the eye piece must, therefore, always be turned which is inconvenient. Besides these objections it cannot be applied to Telescopes supported on stands, for these are moved by rack and pinion; and as the Pearl cannot turn on its axis, angles can be measured only in one direction.

But these disadvantages are not experienced in the circular Pearl Micrometer, invented by Dr. Brewster. "This Micrometer, which I have often used," says its learned inventor, "both in determining small angles in the heavens, and such as are subtended by terrestial objects," is represented below, which exhibits its ap-



pearance in the focus of the first eye glass. The outer portion is the diaphragm, and its interior circumference is Mother of Pearl, graduated into 360 equal parts. The outer edge of the Pearl is not, as would appear, immediately connected with the diaphragm, but to the end of a tube which moves between the third eye glass, and the diaphragm. The angle subtended by the diameter of the interior surface of the micrometer must be determined by measuring a base, and the angle subtended by any number of degrees may be determined by a table. The method of constructing this table the inventor has described.

CHAPTER IV.

On Microscopes.

It is uncertain who invented the Microscope; the candidates for the honour are so numerous and respectable, and their supporters so worthy attention, it is difficult to determine. Zacharias Janson is the inventor, according to Borellus; but Huygens and others maintain the claim of Cornelius Drebell. It cannot, however, be denied that the testimony of Borellus is most admittable, for he affirms that he saw the first microscope that was made; which was presented to Albert Arch-Duke of Austria. This instrument he describes as being six feet long, and an inch in diameter, and was supported by three brass pillars, in the shape of dolphins, on a base of ebony. This microscope was of course a compound one, but of its construction we have no account.

Microsopes are of three kinds,—single, compound refracting, and compound reflecting. It is well known that the nearer an object is to a spectator the more clearly it is defined; for the larger the angle which an image subtends the larger the object appears. From this we deduce that the nearer an object is brought to the eye the larger it appears.

A single Microscope consists of a convex lens, mounted in that way most convenient for the use of an observer. Place this between the eye and the object, in the focus of the glass, and by this means the diverging rays will be refracted, and those rays, from an object which by their great divergency would not be collected by the crystalline lens of the eye, if the object were too near the eye, are rendered parallel; thus an enlarged and distinct view is obtained.

The single Microscope may be mounted in a variety of ways to suit the purpose required, and receives a variety of names according to its use. There is, therefore, a Botanical, Mineralogical, Anatomical, Aquatic, &c., Microscope, but they only differ in their fitings.

A double convex lens is commonly used for Microscopes, but globules are sometimes employed. The construction of the simple Microscope is now brought to great perfection, for Dr. Brewster relates that he is in possession of lenses whose focal length is one thirtieth of an inch. "We cannot, therefore," he says, "expect any greater improvement, unless from the discovery of a transparent substance which combines a high refractive power, with a low power of dispersion."

Little can be said concerning fluid Microscopes. They consist of a drop of water, or some fluid of higher refractive power, placed in a small perforated plate of metal; by this means forming a double convex lens. Sulphuric acid and castor oil are greatly preferred to water; for, whereas water has a small refractive power and great dispersive, these have a small dispersive power and a large power of refraction. But the best fluids are Canada Balsam, or Balsam of Capari.

By the Compound Microscope an object is doubly magnified; the real image being enlarged by the object glass, and that enlarged image increased by the eye glass. From this it appears the compound refracting microscope consists of two lenses, and the distance at which these are placed from each other must exceed the sum of their foci.

The Amician Reflecting Microscope was invented at Modena, by Professor Amici, and is described in the eighteenth volume of the Transactions of the Italian Society. This instrument consists of a concave ellipsoidal metallic speculum, having its focus at the distance of $2\frac{6}{10}$ inches. At about half its focal distance, a small plane reflector is fixed, and the object to be examined is placed opposite to it, in the focus of the large mirror. The rays after reflection from the large mirror are viewed by an eye piece.

Since the introduction of this instrument into England it has been improved. The focus of the concave mirror is greatly shortened, and the smaller mirror lessened. It has a magnifying power of nearly a million, and is a convenient instrument.

The Solar Microscope may be compared to a magic lantern. The light of the sun being reflected from two plane mirrors, is condensed by lenses, and thrown on an object, a magnified image of which is formed by a lens. This is, perhaps, one of the most useful microscopes we possess, and may be constructed by an ingenious student.

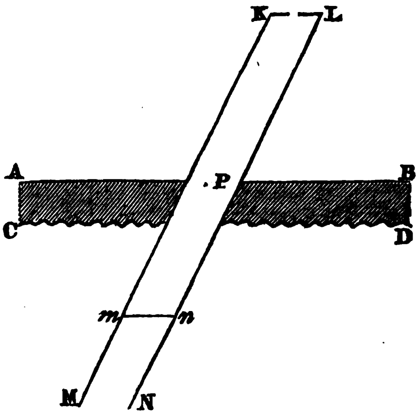
Dr. Brewster's opinion on the improvement of single microscopes has already been alluded to. In the last number of the Journal of Science, an interesting account of the Single Lens Microscopes, of Sapphire and Diamond, executed by Mr. A. Pritchard, appeared. "The first diamond lens," says the author of that paper, "was completed in the year 1824." The focal distance of this magnifier is about one thirtieth of an inch, and is double convex. Of the value and importance of the introduction of this brilliant substance for the formation of single Microscopes, Dr. Goring states, " I conceive the diamond lens to constitute the ultimatum of perfection in the single microscope." But the reader is referred to that paper, and also to " The Natural History of several new living objects for the Microscope, conjoined with accurate descriptions of the Diamond and Sapphire, Aplanatic and Amician Microscopes, by Dr. Goring and Mr. Pritchard."

CHAPTER V.

On Instruments used for Optical Observations on and under Fluids, &c.

Dr. Brewster has given a truly interesting account of an instrument for viewing objects under water, in the fourth book of his Treatise. This was suggested to him, as he informs us, by a notice in one of the Philosophical Journals, that the Academy of Science, at Copenhagen, had offered the mathematical prize to the inventor of a hydraulic tube, by means of which objects might be distinctly seen at the bottom of the sea.

The simple construction and effective application of this instrument make it peculiarly valuable. Let A B be a block of wood floating on the surface of ruffled water, C D and K L M N, be a tube inserted in it, having a motion round the point P. Near the lower extremity of the tube, cement a piece of well polished plate glass, *mn*, to prevent the rise of water. When this



instrument is plunged into the sea, and directed to any object at the bottom, it may be distinctly seen; for the water, pressing against the glass, *mn*, the rays from that object are received into the eye, without suffering any important change.

If the depth of water prevent objects from being distinctly seen with this instrument, it is only necessary to remove the tube and supply a telescope. There is, however, a method of making the tube subservient to every purpose, but the experiments I have made are not sufficient to warrant a risk of an explanation, as farther observations may yet more advance the value of the instrument.

By this fortunate invention the contents of mighty waters are brought before our view, and the secrets of the abyss laid open. To the naturalist and geologist this instrument is peculiarly important, but has not received the attention it demands. It is also adapted for the purposes of amusement; for that recreation is most rational with which we can connect the advantages of science.

It now only remains to describe the instruments which have been invented for the important purpose of measuring the refractive and dispersive powers of fluids. "There is, perhaps," says Dr. Brewster, "no part of Natural Philosophy more truly interesting than that which relates to the determination of the physical properties of bodies. An accurate knowledge of these properties is of extensive use in the Arts and Sciences, and has conducted the experimental philosopher to some of the finest inventions and discoveries of which the human mind can boast. In the ardour of research, by which the last century was characterised, investigations of this kind were by no means overlooked, though they were in a great measure confined to the mechanical properties of opaque bodies. It is only of late years that philosophers have turned their serious attention to the powers of transparent substances in refracting and dispersing the rays of light; and, though the improvement of optical instruments is involved in the inquiry, yet this branch of physics must be regarded as still in its infancy. Every attempt, therefore, however humble, of facilitating the determination of refractive and dispersive powers, or of confirming and correcting the results obtained by preceding authors, is entitled to the particular attention, both of chemists and experimental philosophers."

The instrument, which Dr. Brewster has invented for the measurement of refractive powers, and used so successfully himself, consists of a compound microscope. At the extremity at which the object glass is placed, a piece of thin glass is fastened perpendicular to the axis of the microscope. In a small tube a double convex lens is placed, in such a manner that it may be brought into contact with the glass. Between the lens and the plane glass, substances may be introduced, and will certainly form a plano-concave lens. Even if the substance be not a liquid, by means of a screw it may be pressed, between the lens and glass, so extremely thin as to be completely diaphanous at the centre. With this instrument the inventor compiled his important Table of Refractive Powers, which it is not improper to extract, being omitted under Refraction. Another Table is also in part given, formed from the observations of various authors, which shows the truth of Mr. Herschel's remark,—the whole stands in need of a radical investigation. Previous to this, we extract a curious Table on

The Refractive Powers of Vegetable Juice.

Juice of the Fruit of a ripe Orange newly taken out	2.392
Ditto, after standing several days	3.433
Juice of the Conium Maculatum, or Common Hemlock	2.390
Ditto, after standing 6 hours, 50 minutes	3.317
Juice of the Angelica Sylvestris	2.393
Ditto, after standing 4½ hours	3.334
Juice of the Sanguinaria Canadensis	2.398
Ditto, after standing 12 hours	3.387
Juice of the Lactuca Virosa	2.354
Ditto, after standing 10 hours	3.400
Weak Infusion of Senna	2.353
Ditto, after being exposed to the air 9 hours	3.412
Juice of the Asarum Europeum	2.433
Ditto, after standing several hours	3.648
Ditto, after standing 18 hours	3.949
Juice of the Ranunculus Flammula	2.399
Ditto, after standing 7 hours	3.337
Juice of the Sedum Telephium	2.387
Ditto, after standing 14 hours	3.412

These experiments can be of little value, except on account of their singularity. But it is a remarkable circumstance, that a great coincidence is observed in all; for they seem to differ but little, either in their aqueous parts, or the residuum after evaporation.

Table of Refractive Powers.

	Index of Refrac. according to Dr. Brewster.	Index of Refrac. according to various experimentalists.
Chrom. Lead, greatest Refraction	2.974	2.972
Ditto, another kind	2.926	
Realgar	2.549	
Chrom. Lead, least Refraction	2.503	2.500
Ditto, another kind	2.479	
Diamond brown coloured	2.487	2.439
Diamond, a different one	2.470	
Phosphorus	2.224	2.224
Glass of Antimony	2.216	2.200
Sulphur, native	2.115	2.038
Sulphur, melted	2.148	
Carb. Lead, greatest Refraction	2.084	
Carb. Lead, least Refraction	1.813	1.805
Sulphate of Lead	1.925	
Garnet	1.815	
Blue Sapphire	1.794	
Pryrope	1.792	
Jargon	1.782	
Rubellite	1.779	1.768
Spinelle Ruby	1.761	1.756
Chrysoberyl	1.760	
Cinnamon Stone	1.759	
Axinite	1.735	1.733
Deep Red-coloured Glass	1.729	1.720
Epidote, greatest Refraction	1.703	
Epidote, least Refraction	1.661	1.659
Boracite	1.701	
Carb. of Strontites, greatest Refraction	1.700	1.703
Carb. of Strontites, least Refraction	1.543	
Orange coloured Glass	1.695	
Chrysolite, greatest Refraction	1.685	1.686
Chrysolite, least Refraction	1.668	

	Index of Refrac. according to Dr. Brewster.	Index of Refrac. according to various experimentalists.
Tourmaline	1.668	
Calcareous Spar, greatest Refraction	1.665	
Calcareous Spar, least Refraction	1.519	1.483
Sulph. of Barytes, greatest Refraction	1.664	
Ditto, Ordinary Refraction	——	1.6460
Spargel Stone	1.657	
Red Topaz	1.652	1.640
Glass Hyacinth, red	1.647	
Sulph. of Strontites	1.644	
Oil of Cassia	1.641	
Yellow Topaz	1.638	1.621
Blue Topaz from Aberdeenshire	1.636	
Opal-coloured Glass	1.635	
Balsam of Tolu	1.628	
Castor	1.626	1.619
Muriate of Ammonia	1.625	
Bluish Topaz from Cairngorm	1.624	
Guiacum	1.619	
Flint Glass	1.616	1.625
Green-coloured Glass	1.615	
Purple-coloured Glass	1.608	
Flint Glass, another kind	1.604	1.590
Oriental Ruby	1.601	
Oil of Aniseeds	1.601	
Beryl	1.598	
Balsam of Peru	1.597	
Flint Glass, a third kind	1.596	1.578
Gum Ammoniac	1.592	
Tortoise Shell	1.591	
Emerald	1.585	1.570
Balsam of Styrax	1.584	
Bottle Glass	1.582	1.582
Tartaric Acid, greatest Refraction	1.575	
Tartaric Acid, least Refraction	1.518	
Glass pink-coloured	1.570	1.554
Horn	1.565	

	Index of Refrac. according to Dr. Brewster.	Index of Refrac. according to various experimetalists.
Rock Crystal	1.562	
Amethyst	1.562	1.556
Gumastic	1.560	
Burgundy Pitch	1.560	
Resin	1.559	1.558
Chio Turpentine	1.557	
Rock Salt	1.557	
Sugar, after being melted	1.555	1.554
Gum Thus	1.554	
Chalcedony	1.553	
Sulph. of Copper, greatest Refraction	1.552	
Sulph. of Copper, least Refraction	1.531	1.527
Copal	1.549	
Canada Balsam	1.549	1.541
Eleme	1.547	
Olibanum	1.544	
Phosphoric Acid, solid	1.544	
Crown Glass	1.544	1.526 1.5301
Gum Juniper	1.538	
Selenite, greatest Refraction	1.536	
Feldspar	1.536	
Crown Glass, a different kind	1.534	
Caoutchoric	1.534	1.530
Oil of Sassafras	1.532	1.534
Balsam of Capivi	1.528	
Leucite	1.527	
Plate Glass	1.527	1.5133
Citric Acid	1.527	1.525
Shell Lac	1.525	
Gum Myrrh	1.524	
Gum Dragon	1.520	
Gum Arabic	1.512	1.502
Sulph. of Potash	1.509	1.502
Oil of Cummin	1.508	
Stilbite	1.508	

	Index of Refrac. according to Dr. Brewster.	Index of Refrac. according to various experimentalists.
Nut Oil	1.507	1.490
Oil of Pimento	1.507	
Oil of Sweet Fennel Seeds	1.506	
Oil of Rhodium	1.505	1.500
Balsam of Sulph.	1.497	
Sulph. of Iron, greatest Refraction	1.494	1.496
Oil of Angelica	1.493	
Oil of Marjoram	1.491	
Oil of Caraway Seeds	1.491	1.480
Castor Oil	1.490	1.462
Obsidian	1.488	
Oil of Hyssop	1.487	
Oil of Feugreck	1.487	
Cajeput Oil	1.483	1.480
Oil of Almonds	1.483	
Oil of Savine	1.482	
Oil of Pennyroyal	1.482	
Oil of Lemon	1.481	1.379
Oil of Spearmint	1.481	
Oil of Thyme	1.477	
Oil of Dill Seed	1.477	
Oil of Turpentine	1.475	1.486
Rape Seed Oil	1.475	
Borax	1.475	
Oil of Juniper	1.473	1.472
Oil of Brick	1.471	
Oil of Bergamot	1.471	
Oil of Olives	1.470	1.4705
Spermaceti Oil	1.470	
Oil of Rosemary	1.469	1.452
Oil of Poppy	1.463	
Oil of Lavender	1.457	1.462
Oil of Chamomyle	1.457	
Oil of Wormwood	1.453	
Hydrophosphoric Acid	1.442	
Sulphuric Acid	1.440	1.430

	Index of Refrac. according to Dr. Brewster.	Index of Refrac. according to various experimentalists.
Flour Spar	1.436	1.434
Oil of Rhue	1.433	
Nitric Acid	1.406	1.410
Nitrous Acid	1.396	
Muriatic Acid	1.376	1.392
Alcohol	1.374	1.372
Oil of Ambergrease	1.368	1.361
White of an Egg	1.361	
Jelly Fish	1.345	
Cryolite	1.344	1,349
Salt Water	1.343	
Water	1.335	1.3358
Ice	1.307	1.308

An instrument for measuring the dispersive powers of solid and fluid substances has been long desired. But many pressing difficulties have prevented the completion of a simple and effective instrument for that purpose. Many philosophers have endeavoured to construct a prism with a variable refracting angle, and several have partially succeeded, but neither simplicity nor accuracy, the greatest recommedations to all philosophical instruments, have characterised their attempts. Clairaught and Boscovich, men of whom their countries boast, have formed instruments of this kind. That invented by Clairaught was a plano-cylyndrical lens, the cylindrical surface, making different angles with the plane side. But a great dispersion of the refracted rays must result from transmitting a beam of light through the prism.

Abat, an Optician, at Marseilles, thought to remedy this objection by joining a plano-cylindrical concave lens, with a plano-cylindrical convex lens. But this instrument also has many disadvantages, viz., the friction between, and reflections at, the surfaces, &c. Dr. Brewster has, however, supplied us with an instrument which is free from many errors to which others are subject. The reader will find an interesting description of it in the Doctor's Treatise on New Philosophical Instruments; a book which should be in the hands of all who are anxious to acquaint themselves with the application of optical science.

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